Series II, Volume 3 May 1, 1958 Number 3

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1958 SPRING MEETING

AT

WASHINGTON, D. C.

MAY 1, 2, AND 3, 1958

PUBLISHED BY THE AMERICAN PHYSICAL SOCIETY, COLUMBIA UNIVERSITY, NEW YORK 27, NEW YORK
EIGHT ISSUES EACH YEAR

BULLETIN

of the

AMERICAN PHYSICAL SOCIETY

Published eight times per year

Subscription price: $5.00 per year

Single copies: $1.00 each

The Bulletin of the American Physical Society is published eight times a year, once in January, once in March, once in April, once in June, once in August, once in September, once in November, and once in December, at Prince and Lemon Streets, Lancaster, Pennsylvania. Correspondence should be addressed to American Physical Society, Columbia University, New York 27, New York.

Entered as second class matter, December 27, 1949, at the post office at Lancaster, Pa., under the Act of August 24, 1912.

Acceptance for mailing at a special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized Nov. 30, 1948.

Table of Contents

Programme of the 1958 Washington Meeting:

Preamble 158

Epitome 161

Main Text 162

Index 234

Announcement of the 1958 June Meeting (Ithaca) 238

Announcement of the 1958 August Meeting (Vancouver) 239

Calendar of prospective meetings and deadlines 240

Instructions for the preparation of abstracts .. 240

Minutes of the 1957 Thanksgiving Meeting ... 241

Minutes of the 1957 December Meeting 243

Minutes of the 1958 Annual Meeting 243

Advance reservation form for the Washington banquet 247

May 1, 1958 Series II, Vol. 3, No. 3

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1958 Washington Meeting, May 1, 2, and 3, 1958

THE **1958 Spring Meeting** of the American Physical Society will be held in **Washington, D. C., on Thursday, Friday, and Saturday, May 1, 2, and 3.** The scientific sessions will be distributed, as they were last year, between the Sheraton-Park Hotel, the Shoreham Hotel, and the National Bureau of Standards. The meeting, as measured by number of papers contributed and invited, is of about the same proportions as last year's: whether the future reserves for us such an amazing and troublesome gain in attendance as surprised us at the 1957 and 1958 Annual Meetings in New York is something that remains for the future to tell. R. D. Huntoon has accepted for the fourth time the tremendous burdens of the Chairmanship of the Local Committee: his committeemen are D. F. Bleil, W. C. Hall, A. I. Mahan, J. H. McMillen, S. F. Singer, L. Slack, G. Temmer, and W. R. Tilley—it will be seen that the major institutions of Washington have given generously of their aid.

Last-minute correspondence to officers of the Society, to chairmen of sessions, and to members generally should be addressed in care of the Chairman of the Local Arrangements Committee, Rooms 106–108C, Sheraton-Park Hotel, Washington 8, D. C.

(The foregoing is copied almost verbatim from the corresponding Bulletin of 1957: this shows how lucky we have been in standardizing the arrangements for our Washington meeting, and also how regularly the burden is graciously assumed by the same people, to whom our debt goes up and up. This luck is apparently not destined to continue, and in fact there will be alterations even in the remainder of this foretext, one of them involving the registration fee.)

Hotel. Room reservations, as mentioned in previous issue of this Bulletin, should be made by writing to the Sheraton-Park Hotel, Washington 8, D. C., with mention that the writer is coming to the convention of the American Physical Society. Late writers will find themselves assigned to other hotels. The Sheraton-Park wishes to communicate that it has suites available which, if shared, will cost less or not more than single-room rates to the individuals: parlor and one-bedroom suites at $7 and $9 per night per person for three and for two people sharing, parlor and two-bedroom suite at $6 and $8 per night per person for six and for four people sharing.

Even with the best will in the world, a hotel cannot always fulfil a confirmed reservation when the maker thereof does not arrive until late in the day. Get there as early as possible, and if not "roomed" at once, go back from time to time during the day instead of waiting till evening. A deposit made in advance is often helpful.

The **main registration desk** will be located in the Sheraton-Park and an **ancillary desk** in the Shoreham. You may register at either, and everyone is required to register and pay the registration fee. This fee may be as low as one dollar or as high as two. The expenses of the Washington meeting are creeping up on us, and the amount to be charged will depend upon the estimate of these. Dinner tickets may be bought at either desk; but the glackboards with notice of messages, post-deadline papers, and information about possible changes of halls will be found only at the Sheraton-Park.

Our **two most recent Nobel Laureates,** T. D. Lee and C. N. Yang, will lecture in Sheraton Hall on Friday morning on the topics which, needless to say, raised them to their eminence.

A **Symposium on experiments designed to promote thermonuclear effects** will be held on Friday afternoon in Sheraton Hall. The participants will be R. F. Post, Lyman Spitzer, and Albert Simon. It might be a good idea to forego luncheon for the sake of a seat at this event.

Our **Division of Fluid Dynamics** has arranged a group of invited papers to be given on Thursday morning in the West Ballroom of the Shoreham.

A **photonuclear conference** under the management of H. W. Koch is to begin on the day before our meeting, and **its Symposium** figures in this Bulletin as Session DA on Thursday morning, while ten-minute papers in its field have been assigned to Session E of our meeting on Thursday afternoon. At the request of its management we have situated these sessions at the National Bureau of Standards, although the custom of the Washington meeting has been to put nuclear-physics papers at the hotels.

Invited papers on the general programme are by R. E. Bell, P. L. Bender, Felix Boehm, R. O. Bondelid, D. A. Bromley, J. W. Butler, J. C. Eisenstein, G. A. Harrower, N. M. Hintz, R. Jastrow, L. H. Johnston, W. M. MacDonald, Hans Mark, J. J. Murray, O. Oldenberg, W. K. H. Panofsky, Author Roberts, A. W. Saenz, R. M. Talley, R. K. Wangsness, and M. Zelikoff.

Four hundred and four abstracts of ten-minute papers appear in this Bulletin. The totals of the previous four years were 406, 393, 394, and 408. They are distributed among 33 sessions, and in addition there are eight sessions of invited papers only.

As there are more invited papers than last year, and on Saturday fewer good halls, the problems of making up the programme have been more severe. A new complication is the desire of two groups to hold their Symposia on Thursday morning (wherefore *eight* sessions on that half-day, a record!), and an old complication better realized than heretofore is the demand of the hotels and the Bureau that all meeting rooms be vacated by 5 P.M.—Sheraton Hall even by 4.30 P.M. Owing to this last stipulation many of the afternoon sessions are scheduled to begin at eccentrically early hours, and even some of the morning sessions which must be over in time for the afternoon ones to begin. Sixteen-paper sessions, though rare, are unfortunately not absent from this meeting; neither are coincidences between sessions of similar interest nor papers separated from their most congenial neighbors because there was not room in a single session. For instance, there are some low-temperature-physics papers not in the session labeled "cryogenics." Experimental papers bearing on the nonconservation of parity, last year assembled, are this year distributed among sessions according to the techniques employed. The Secretary gratefully acknowledges the invaluable help of Robert Serber who arranged the theoretical papers and the Deputy Secretary who arranged most of those classed under nuclear reactions and neutron physics.

As usual, there were a score or more of abstracts that arrived late, with postmarks attesting that they were still at the point of origin on deadline-day, or that on the day before deadline-day they were still at postoffices in the West. They will not be found here. Perhaps the prominence lately accorded to "time-reversal" has led some people to suppose that an abstract may be received at this office before it is posted. We understand that there is no basis in theory for such a conclusion, and certainly there is none in fact.

The **banquet of the Society** will be held on Friday evening at seven in the Terrace Room of the Shoreham Hotel—same place as last year. The after-dinner speakers will be announced on the blackboards near the registration desk if not in this Bulletin. A reservation form will be found on page 247 of this Bulletin. Please use it, for the hotel requires this year a statement of guaranteed attendance by 5 P.M. on *Thursday*. Only a small increase will be allowed subsequently. Tickets reserved by mail will be held at the registration desk. If you cannot reserve by mail, *be sure to buy your tickets on Thursday*. Price of the tickets, $4.50.

The American Institute of Physics will conduct a **Placement Service Register** at the Hotel Shoreham on May 1 and 2. The Register will be open from 9 A.M. to 6 P.M., Thursday and Friday only.

As in prior years, the American Institute of Physics will conduct a **book exhibit** in the foyer adjacent to Sheraton Hall. Several leading technical publishers will exhibit their latest texts, and everyone is cordially invited to browse.

The **ladies' programme** has been arranged by Mrs. Carl L. Frederick. There will be two scheduled tours on Thursday, May 1, at 1:00 P.M. The first will include a tour of the Mosque and the National Cathedral. The second will provide an interesting tour of the Dumbarton Oaks Gardens. Transportation will be provided, and those interested should submit their choice to the ladies' registration desk by 11:30 A.M. on Thursday.

On Friday, May 2, the wives of the local members will provide transportation for a tour of either Mt. Vernon or a general view of Washington, including Old Georgetown and parts of residential areas. Upon completion of the tour, each group will be driven directly to the Army and Navy Country Club for luncheon. The selection of the tour desired must be announced at the time the luncheon tickets are purchased at the ladies' registration desk; the deadline is 5:00 P.M. Thursday, May 1.

Tea. The staff of the National Bureau of Standards will be host to the Society at tea, which they will offer to the members and guests of the Society

at the Manse (on the Bureau grounds) from 4:30 P.M. to 6:30 P.M. on Thursday.

The **Council of the American Physical Society** will meet on Wednesday, April 30, at 10:30 A.M., in the Tamerlane Room of the Shoreham Hotel unless contrary notice is given to its members by special message.

The **Nominating Committee of the American Physical Society** will meet at 4:00 P.M. on Thursday, May first, in the Green Room of the Shoreham Hotel unless contrary notice is given to its members by special message. The Nominating Committee consists of H. D. Smyth, *Chairman*, John Bardeen, N. E. Bradbury, C. D. Coryell, F. N. Frenkiel, M. Goldhaber, S. A. Goudsmit, M. H. Hebb, and E. M. McMillan.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special significance, will be considered for admission to the programme if the abstracts are received at the office of the Society not later than Friday, April 25. The titles of such papers as may be accepted will be written on a blackboard near the registration desk. Part of Session TA has been set aside for them, but a few may be assigned to other places, though the length of most of the other sessions is such as to make additions undesirable.

Prospective meetings and deadlines of the Society are listed on page 240 of this Bulletin, and on pages 238 and 239 appear preliminary announcements of the Summer Meetings in the East (Ithaca) and in the West (Vancouver).

Instructions for the preparation of abstracts are printed on page 240 of this Bulletin. Members should make a point of reading these instructions whenever a new issue of the Bulletin appears, for they occasionally change in the direction of greater stringency. Their general purpose is to reduce the labor and the time spent by the staff of the American Institute of Physics in "editing" the abstracts for the printer. It is strange how many of our members still type their abstracts without having observed that in print the title always comes first, then the author's name or names in capitals, then his or their institution in lower-case italics.

Errata pertaining to abstracts in this issue will be published in a later issue of this Bulletin if received not later than Monday, May 5, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in the abstract with erasures and alterations. Write out your corrections in the form "Instead of . . . read . . . ." The privilege of having an erratum published is not accorded to enable people to publish new results or to restore material that was cut out because the abstract was too long.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1958 WASHINGTON MEETING

(Personal names are those of invited speakers. NBS stands for National Bureau of Standards, SP for Sheraton-Park Hotel)

Thursday Morning

9:45	A	Strange particles I. SP, Sheraton Hall.
9:45	AA	Division of Fluid Dynamics: Clauser, Burgers, Sherman, Sterne. Shoreham, West.
10:00	B	Neutron physics I. SP, Burgundy.
10:00	BA	Nuclear magnetic resonance. SP, Continental.
9:45	C	Accelerators I. SP, Caribar-Mural.
9:45	CA	MacDonald, Bondelid, Butler, Johnston. Shoreham, Main.
9:45	D	Theoretical physics I, including field theory. NBS, Materials Testing.
9:45	DA	Symposium of Photonuclear Conference: Brown, Jensen, Marshak, Smith. NBS, East.

Thursday Afternoon

1:45	E	Photonuclear phenomena. NBS, East.
2:00	EA	Strange particles II; Panofsky, Murray. SP, Sheraton Hall.
2:00	F	Neutron physics II. SP, Burgundy.
1:45	FA	Paramagnetic resonance; cyclotron resonance. SP, Continental.
2:00	G	Accelerators II; other instrumentation. SP, Caribar-Mural.
2:00	GA	Bell, Hintz, Mark, Bromley. Shoreham, Main.
2:00	H	Theoretical physics II, including nuclear forces. NBS, Materials Testing.

Friday Morning

9:15	J	Atomic-beam experiments; Bender, Roberts. SP, Continental.
9:15	K	Nuclear reactions I. SP, Caribar-Mural.
9:30	KA	Harrower, Jastrow, Zelikoff, Oldenberg. Shoreham, Main.
9:15	L	Neutron physics III. SP, Burgundy.
9:15	LA	Metals. NBS, East.
9:30	M	Magnetism. Shoreham, West.
9:30	MA	Yang, Lee. SP, Sheraton Hall.

Friday Afternoon

1:45	N	Post, Spitzer, Simon. SP, Sheraton Hall.
1:45	NA	Pions and muons. Shoreham, West.
2:00	P	Nuclear reactions II. SP, Continental.
2:00	PA	Theoretical physics III, including statistical and low-temperature theory. SP, Caribar-Mural.
2:15	Q	Wangsness, Saenz, Talley, Eisenstein. NBS, East.
2:00	R	Proton-proton scattering; proton polarization; Boehm. Shoreham, Main.
2:15	RA	Unstable nuclei I. SP, Burgundy.

Friday Evening

7:00 Banquet of American Physical Society. Shoreham, Terrace.

Saturday Morning

9:30	S	Unstable nuclei II. SP, Burgundy.
9:15	T	Nuclear reactions III. SP, Continental.
9:15	TA	Fluid dynamics; post-deadline papers, if any. Shoreham, Main.
9:15	U	Microwave and optical spectroscopy. SP, Exhibit.
9:15	V	Theoretical physics IV: mesons and hyperons. Shoreham, West.
9:00	VA	Semiconductors. NBS, East.

Saturday Afternoon

1:30	W	Cosmic rays; astrophysics. Shoreham, West.
1:30	WA	Theoretical physics V: nuclear theory. SP, Exhibit.
1:45	X	Cryogenics. SP, Burgundy.
2:00	XA	Nuclear reactions IV, including fission. Shoreham, Main.
2:00	Y	Positronium; muonium; various nuclear topics. SP, Continental.
1:30	Z	Solid-state physics, mostly nonmetals. NBS, East.

PROGRAMME

THURSDAY MORNING AT 9:45

Sheraton Hall

(W. K. H. PANOFSKY presiding)

Strange Particles I

A1. High-Energy Nuclear Collisions above 10^{13} ev.* MARCEL SCHEIN AND MARTIN W. TEUCHER, *University of Chicago.*—In a 16×8-in. stack of 100 nuclear emulsions, each 600 μ thick, which was flown for 7 hr near Guam (Marianas Islands, 6°N geomagnetic latitude) at an altitude of 102 000 ft, two very high-energy nuclear interactions of $E>10^{13}$ ev were located. The primary particle of the first one ($3+52p$) forms an angle of 5° with the plane of the emulsion. The primary energy is estimated to be about 4×10^{13} ev. In the forward cone of the center-of-mass system, 12 secondary interactions were caused by charged particles of $E>50$ Bev and only one by a neutral particle of $E>50$ Bev. In the backward cone of the primary collision, individual tracks could be followed through, yielding 10 stars and 3 single scatterings. The average number of heavy prongs per star is 2.3 (in these 10 stars). The second event has an energy estimated to be greater than 10^{14} ev and is originated by an α particle forming an angle of 9° with the plane of the emulsion. Mean free paths for particles in the forward and backward cones will be given for both events and the nature of the particles will be discussed.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by the National Science Foundation.

A2. Heavy Nuclei Interactions Yielding Monoenergetic Nuclear Particles of $E\sim10^{12}$ ev.* MARTIN W. TEUCHER, *University of Chicago.*—In the Guam stack, all the incoming heavy nuclei of $Z>2$ were followed through the stack. In most cases the heavy nucleus undergoes a nuclear collision and splits into nuclear fragments of similar mass, in particular, α particles. At very high energies, protons are frequently observed. One heavy nucleus of charge $Z=9\pm1$ could be observed which undergoes an interaction yielding a nuclear fragment of $Z=6\pm1$ and 12 well-collimated minimum tracks. The fragment interacts again after 15 cm, yielding an α particle and about 60 minimum tracks. After another 13 cm, the α particle finally produces an event $0+17\alpha$. The angular distribution of the minimum tracks in the three break ups indicate energies of 10^{12} ev per nucleon. All minimum tracks were followed through the stack. By this method, 25 secondary interactions could be located. 4 of these were found to have energies close to 10^{12} ev. This strongly suggests that the primary particles producing these events are protons originally belonging to the primary heavy nucleus. The events will be discussed in detail and values of the mean free paths of secondaries will be given.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

A3. Analysis of Heavy Fragments Emitted in Cosmic-Ray and 6.2-Bev Proton Stars.* A. G. BARKOW, *Marquette University,* G. KANE, *Manhattan College,* Z. O'FRIEL, *St. Bonaventure University,* AND R. E. MCDANIEL, *University of New Mexico A. and M.*—A preliminary report on the analysis of over 1000 heavy fragments from stars produced by cosmic rays and 6.2-Bev protons. The charges of the heavy fragments were determined by measuring thin down length and checked by delta-ray counts. The measurements indicate that the width of the track is proportional to Z^4. Heavy fragments up to a charge of $Z=7$ have been found. The energy distribution curves for the low Z's (Li, Be) agree nicely with the curves deduced from the evaporation model assuming appropriate nuclear temperatures and Coulomb barrier heights. Angular distribution curves indicate isotropic emission. The study of Li^{-8} fragments suggest a most probable energy of 18 ± 2 Mev. A distinct second peak is observed at an energy of 50 Mev. It is impossible to explain the second peak on the basis of fragmentation from light nuclei.

* Work supported by the National Science Foundation.

A4. Search for Mass-550 Particles. I. Apparatus.* R. L. CALL, W. H. SANDMANN, AND J. W. KEUFFEL, *University of Utah.*—An apparatus has been designed to search for the mass-550 particles reported by Alikhaniyan *et al.*[1] Particles are selected by an incident telescope consisting of beam-defining counters, a Čerenkov anticoincidence counter, and a thin scintillator S_1. The particles stop in a thin-walled 64-kg scintillator S_2 enclosed below by a scintillatory jacket in anticoincidence. From the S_1 and S_2 pulses one obtains the velocity and energy of the particle and hence the mass. The Čerenkov threshold is such that μ and π mesons have a limited range, and may be completely eliminated by a suitable bias on S_2; meson leakage is easily recognized by the characteristic 2.2-μsec pulse in S_2. The proton peak has a width of about 30%. Each even is investigated for evidence of decay secondaries from 0.1 μsec to 0.07 sec using a special scope presentation. The rate of μ mesons entering the apparatus and stopping in the same range interval as would be accepted for mass-550 particles is 500 day^{-1}. (In an actual run the μ's are rejected by the Čerenkov.)

* Assisted by the National Science Foundation and the University Research Committee.

[1] Alikhaniyan *et al.*, Zhur. Eksptl. i Teoret. Fiz. 31, 955 (1956).

A5. Search for Mass-550 Particles. II. Results.* J. W. KEUFFEL, R. L. CALL, AND W. H. SANDMANN, *University of Utah.*—The mass spectrum of cosmic-ray particles at 4700 ft is being studied with and without a 6-in. Pb filter in the incident telescope of the apparatus described in the preceding abstract. Without Pb, there is a flat background in the mass spectrum due to protons which interact in S_2 with some energy escaping as neutrons. From *this* run the abundance of mass-550 particles (here denoted X particles) relative to μ mesons in the same range interval is $<0.25\%$. Under Pb, the proton peak and flat background are reduced by a factor of 6. In a run of 564 hr we see a peak of 15 particles in the neighborhood of mass 650, where 8 would be expected from background (an abundance of 0.18%); 5 of the 15 events exhibit a decay where 2 would be expected, the decays being spread over 0.07 sec. There is no evidence for $X-\mu$ or $X-\pi-\mu$ decays, which are detected with very high efficiency; hence, if the peak is real, an $X-e$ decay mode is suggested. The experiment is continuing.

* Assisted by the National Science Foundation and the University Research Committee.

A6. $\bar{\theta}^0$ Interactions at Large Distance from Production of θ^0.* YASH PAL, E. BOLDT, H. BRIDGE, AND D. O. CALDWELL, *M.I.T.*—During an investigation of properties of heavy unstable particles produced by negative pions in the iron plates of a large multiplate cloud chamber, we have observed about a dozen cases of hyperon production by neutral particles.

These interactions are believed to be produced by long-lived θ_1^0 particles by their $\tilde{\theta}^0$ mode. The characteristics of the interactions are very similar to those of negative K particle interactions. In 4 cases a charged pion is directly identified as one of the interaction products, while still another one shows evidence of π^0 production. Thus all interactions are consistent with the hypothesis that: $\theta_2^0+N\rightarrow Y+\pi$, which would suggest that the interaction occurs predominantly with single nucleons. Comparison of the expected total number and spatial distribution of $\tilde{\theta}^0$ interactions with experimental observations shows a quantitative agreement with the main features of the particle mixture theory of Gell-Mann and Pais.[1] Evidence will be presented which enables one to put limits on the mass difference between θ_1^0 and θ_2^0 particles.

* This research is supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] M. Gell-Mann and A. Pais, Phys. Rev. **97**, 1387 (1955).

A7. Interaction of 250–300 Mev K^+ mesons with Emulsion Nuclei. E. Helmy, J. H. Mulvey, D. J. Prowse, and D. H. Stork, *University of California, Los Angeles*, M. Grilli, L. Guerriero, M. Merlin, and P. O'Friel, *University of Padova, Italy*, D. Evans, F. Hassan, K. K. Nagpaul, M. Shafi, and A. Wataghin, *University of Bristol, England*.—A considerable meterage of K^+-meson track length has now been followed between the energy limits 250–300 Mev in a stack exposed to the separated high-energy K beam at the Berkeley Bevatron. Based on about 50 meters, the mean free path for inelastic scattering is about 55 cm. A larger proportion of events in which the K^+ meson does not re-emerge are found at this energy that at lower energies (~100 Mev), a larger proportion also appear to be double scatterings of the K^+ meson within the nucleus. The K-H cross section based on very few events appears to be quite close to the value of 15 mb obtained at lower energies. More accurate values for the mean free path and further details on the K^+ meson interaction with nucleons will be presented together with details of any particularly interesting events.

A8. Further Example of Anomalous K^+ Meson Decay. D. J. Prowse, *University of California, Los Angeles*, and D. Evans, *University of Bristol, England*.—In a systematic study of K^+ meson secondaries, one example has been found in which the charged product is a pi meson of 61 Mev. This must be compared with the example published by the Columbia group[1] in which the pi meson energy was 60 Mev. Both are probably due to the decay mode, $K^+\rightarrow\pi^++\pi^0+\gamma$, although the possibility that they belong to a two-body decay mode, $K^+\rightarrow\pi^++X^0$, where X^0 is a neutral boson and has a mass of 500 ± 5 m_e, should not be overlooked. A description of the event will be given and the interpretation discussed.

[1] Harris, Lee, Orear, and Taylor, Phys. Rev. **108**, 1561 (1957).

A9. Photoproduction of K^+ Particles at Forward Angles.* H. M. Brody, A. M. Wetherell, and R. L. Walker, *California Institute of Technology*.—The method of Donoho and Walker for measuring K^+-particle photoproduction has been improved in order to provide a clearer identification of K^+s and to allow measurements at a more forward angle, 10° in the laboratory. A magnetic spectrometer is used to analyze charged particles from a liquid hydrogen target. K^+ particles are identified by a time-of-flight velocity measurement combined with measurements of the correlated pulse heights in three scintillation counters at the focus of the magnet. In the present measurements a scintillation counter is used to define the aperture of the magnet in such a way as to avoid the possibility of protons (or other particles) scattering from the pole pieces or lead slits and hitting the scintillation counters with a velocity near that of the K particles. This aperture counter is also used in the time of flight measurement instead of a "front" counter near the target, since the latter would be in the beam at the smallest angles. In addition a Čerenkov counter near the magnet focus is used to eliminate fast particles, (π, e, and μ). This counter, together with the time of flight requirements eliminates all but one per thousand of the fast particles.

* This work was supported in part by the U. S. Atomic Energy Commission.

A10. Study of Λ^0 Characteristics Via Decay Proton Measurements.* E. Boldt, H. Bridge, D. O. Caldwell, and Yash Pal, *M.I.T.*—The amplitudes for even and odd parity states in the proton-pion system arising from the decay of a spin $\frac{1}{2}$ Λ^0, are completely specified, to within a common factor, by a measurement of the decay proton polarization.[1] In general, for any spin, the longitudinal polarization of the proton, in the rest frame of an unpolarized Λ^0, is given by:[1] $-\alpha$ (the parity mixing parameter, whose absolute magnitude has been measured in bubble chambers by observing the decay angular asymmetry).[2,3] As an analyzer of such polarization, the asymmetries in the nuclear scattering of Λ^0 decay protons have been measured in a multiplate cloud chamber. The plates are composed of iron, which has a polarization detection efficiency of about 55%[4] for most scattering events selected. The procedure involved in this measurement and results of the data analysis will be presented. Other angular correlations for the decay proton, pertaining to the spin and polarization of Λ^0 hyperons produced in iron by negative pions, will also be reported.

* This research is supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] T. D. Lee and C. N. Yang, Phys. Rev. **108**, 1645 (1957); preprint for Phys. Rev. (1958).

[2] Crawford, Cresti, Good, Gottstein, Lyman, Solmitz, Stevenson, and Ticho, Phys. Rev. **108**, 1102 (1957).

[3] Eisler, Plano, Prodell, Samios, Schwartz, Steinberger, Bassi, Borelli, Puppi, Taaka, Woloschek, Zoboli, Conversi, Franzini, Mannelli, Santangelo, Silvestrini, Glaser, Graves, and Perl, Phys. Rev. **108**, 1353 (1957).

[4] Alphonce, Johansson, and Tibell, Nuclear Phys. **4**, 643 (1957).

A11. Possible Example of the Decay of an Antilambda Hyperon, $\bar{\Lambda}^0$, in Emulsion. M. Baldo-Ceolin, *University of Padova, Italy*, and D. J. Prowse, *University of California, Los Angeles* (introduced by J. R. Richardson).—A stack of emulsion sheets heavily exposed to the 4.5-Bev π^- beam of the Berkeley Bevatron, the π-meson flux being 10^6/sq cm on one side of the stack and falling off by a factor of 10^2 in 6 in., has been area scanned for stopping π^+ mesons. Such mesons had to appear to originate in the part of the emulsion exposed to the most intense beam and to make an angle of less than 30° with the beam direction. Several hundred suitable π^+ mesons have been followed back to their origins and one event has been found which could be the decay of a $\bar{\Lambda}^0$ hyperon. The opening angle of the "V" is 64° and the length of the π^+ meson 1.7 cm. The other particle emanating from the "V" event has an energy of about 200 Mev and it interacts in flight after 3 cm range producing a large star containing 3 shower particles. The interpretation will be discussed and other possibilities considered.

A12. Antiproton Annihilation in Nuclear Emulsion.* Glenn M. Frye, Jr., and Alice H. Armstrong, *Los Alamos Scientific Laboratory*.—Sixteen antiproton annihilation events have been observed in nuclear emulsion, nine at rest and seven in flight, including one already reported.[1] The plates were exposed at the Bevatron in the same geometry as described previously.[2] The average number of charged mesons observed per event is 2.6 ± 0.4, in good agreement with earlier results.[2] Of the seven charged mesons which stop in the stack, two are π^+ and five are π^-. Details of the events and the energies of the mesons and nucleons emitted will be given.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] A. H. Armstrong and Glenn M. Frye, Jr., Bull. Am. Phys. Soc. Ser. II, **2**, 370 (1957).

[2] Barkas, Birge, Chupp, Ekspong, Goldhaber, Goldhaber, Heckman, Perkins, Sandweiss, Segrè, Smith, Stork, van Rossum, Amaldi, Baroni, Castagnoli, Franzinetti, and Manfredini, Phys. Rev. **105**, 1037 (1957).

THURSDAY MORNING AT 9:45

Shoreham, West Ballroom

(F. N. FRENKIEL presiding)

Invited Papers of the Division of Fluid Dynamics

AA1. The Prospects of Magnetohydrodynamics. F. H. CLAUSER, *Johns Hopkins University.* (30 min.)

AA2. Comments on the Application of the Fokker-Planck Equation to Plasma Dynamics. J. M. BURGERS, *University of Maryland.* (30 min.)

AA3. Recent Advances in Rarefied-Gas Dynamics. F. S. SHERMAN, *Office of Naval Research.* (30 min.)

AA4. High-Altitude Atmospheric Density. T. E. STERNE, *Smithsonian Astrophysical Observatory and Harvard University.* (30 min.)

THURSDAY MORNING AT 10:00

Sheraton-Park, Burgundy Room

(H. H. BARSCHALL presiding)

Neutron Physics I

B1. Method of Canceling Energy Fluctuations of a Van de Graaff Ion Beam.* P. B. PARKS, H. W. NEWSON, AND R. M. WILLIAMSON, *Duke University.*—A varying correction voltage is applied to the target which cancels beam energy fluctuations. This correction voltage is a known, constant multiple of a small, variable voltage which must be applied to the outer plate of an electrostatic analyzer to keep the beam centered at the image slits. The inner plate has a constant, negative high voltage. The beam current at the analyzer image slits provides the signal which, when amplified, controls a 2C53 triode which drives both the outer analyzer plate and the target. If the HH^+ beam is put through the analyzer, the unlimited 30 μa H^+ beam may be used for high resolution work. If the H^+ beam is put through the analyzer, it is limited to 2 μa. In either case, the incident energy spread is much better than 1/4000 and may be 1/20 000. The 1.76-Mev $C^{13}(p,\gamma)$ resonance,[1] was used to test performance. We found the upper limit for the width of this resonance to be 250 ev. The most important advantage of our equipment is the ability to use an unlimited beam with high resolution.

* Supported by the U. S. Atomic Energy Commission.
[1] S. S. Hanna and L. Meyer-Schutzmeister, Bull. Am. Phys. Soc. Ser. II, 2, 377 (1957).

B2. High-Resolution Neutron Spectroscopy in the kev Region.* P. F. NICHOLS, E. G. BILPUCH, AND H. W. NEWSON, *Duke University.*—A neutron spectrometer has been designed for maximum resolution attainable with the $Li^7(p,n)$ reaction and a continuous beam from a Van de Graaff accelerator. Keeping in mind the fact that a usable neutron intensity must be maintained, this resolution corresponds to: Li temperature, 440°K; target thickness, 0.4 kev; acceptance angle, $\Delta\theta$, varying between 1.5° and 0.5° at angle, $\theta = 160°$; and proton beam, 20 μA. Proton beam spread should be negligible with the help of the device described in the previous abstract. The resolution and background have been tested with a beam of 2 μA. The calculated energy spreads (about twice those expected from Doppler effect alone) are 500, 260, and 150 ev at neutron energies of 200, 50, and 10 kev, respectively. The measured values determined from a number of narrow resonances are from 1.5 to 2 times as large. We attribute this discrepancy to roughness in the Li targets, and are seeking to improve our target fabrication technique. Scattered neutron background is almost negligible but another side effect (possibly due to scattered protons) is still under study.

* Supported by the U. S. Atomic Energy Commission.

B3. Narrow Neutron Resonances in the kev Region.* E. G. BILPUCH, L. W. WESTON, C. D. BOWMAN, A. K. FURR, P. F. NICHOLS, AND H. W. NEWSON, *Duke University.*—Measurements have been carried out on Bi, Fe, Ba, Ca, and Sr with the apparatus described in the previous abstract and on Ca and Ca^{44} with our older apparatus. No new resonances were observed in Bi, or Fe up to 90 kev except for a weak level at 8 kev, probably in Fe^{56}, which may be responsible for the epithermal capture[1] in natural Fe. Two s resonances were observed in Ca^{44} at 248 and 150 kev and in Ca^{40} three were observed at 220, 170, and 134 in addition to a strong p resonance at 252. High resolution work between 80 and 190 kev showed three weak resonances in Ca^{40} at 83, 87, and 148 kev which are probably not s resonances. Between 17 and 200 kev there are 12 well-defined levels in Sr, only one of which is clearly due to an s wave, while the great majority are clearly due to Sr^{88} and p waves. Between 17 and 120 kev there are apparently s levels in Ba^{138} at 116(0.32), 80(0.23), 69(0.31), 51(0.23), and 32(0.14) kev: the widths in kev are shown in parentheses. Two other resonances at 31 and 74 kev are unidentified. We are developing better methods for determining spin and parity of the narrow well-separated resonances found in the rare-earth elements.

* Supported by the U. S. Atomic Energy Commission.
[1] H. Goldstein, Columbia Conference on Neutron Interactions (1957).

B4. Total Cross Sections for 2–20 kev Neutrons. J. H. NEILER, J. H. GIBBONS, AND W. M. GOOD, *Oak Ridge National Laboratory.*—The fast time-of-flight equipment[1] has been improved in resolution and stability since the most recent report.[2] The fractional energy resolution is 3–3.5%, as determined both from analysis of wide resonances in Fe^{57} and the measured widths of narrow resonances in Cu^{65}. Total cross sections have been measured for neutrons in the energy range 2–20 kev for the following nuclides: Ti^{48}(2.2, 2.5, 15.5), Ti^{49}(2.3, 2.55, 3.6, 7.8), V(4.0, 6.35, 10.5, 12.2, 15.5), Fe^{56}(none),

Fe^{57}(3.7, 5.7), Cu^{65}(2.4, 3.7, 4.2, 6.0, 7.3, 12.4, 16.8), and Zr^{90}(3.6, 12.5, 15.7). Numbers in parentheses are the energies of resonances found in each case. Analyses of these resonances are in process, and those results which have been completed will be presented.

[1] Smith, Gibbons, Good, Neiler, and Banta, Bull. Am. Phys. Soc. Ser. II, 1, 71 (1956).
[2] Gibbons, Good, and Neiler, Bull. Am. Phys. Soc. Ser. II, 2, 217 (1957).

B5. Elastic and Nonelastic Neutron Cross Sections for Beryllium.* J. B. MARION,† J. S. LEVIN, AND L. CRANBERG, *Los Alamos Scientific Laboratory.*—Using a pulsed-beam time-of-flight technique, differential elastic and total neutron cross sections for beryllium have been measured at 2.6, 3.5, 4.1, 5.0, and 6.0 Mev to an accuracy of approximately 5%. In addition, differential inelastic ($Q=-2.43$ Mev) cross sections have been measured at 3.5 and 4.1 Mev to an accuracy of approximately 20%. Nonelastic cross sections, obtained by subtracting the integrated elastic from the total cross sections, are in satisfactory agreement with some of the previous results[1] but not with others.[2] The energy spectra at the higher incident energies clearly show neutrons from the direct $(n,2n)$ reaction. Furthermore, the 2.6-Mev data indicate that this reaction takes place below the threshold for the (n,n') reaction, in disagreement with previous results.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: University of Maryland.
[1] D. J. Hughes and R. B. Schwartz, BNL-325, Supplement No. 1, 1957 (unpublished).
[2] G. J. Fischer, Phys. Rev. 108, 99 (1957).

B6. Fast Neutron Capture Cross Sections.* A. E. JOHNSRUD, M. G. SILBERT, AND H. H. BARSCHALL, *University of Wisconsin.*—Fast neutron capture cross sections were measured as a function of neutron energy by observing induced radioactivities. V^{51}, Mn^{55}, Cu^{65}, As^{75}, Mo^{100}, Ag^{107}, In^{115}, I^{127}, Ba^{138}, Sm^{154}, Dy^{164}, W^{186}, and Au^{197} were investigated at energies between 150 and 2600 kev with a neutron energy spread of the order of 50 kev. The method was similar to that previously described.[1] The activity induced by fast neutrons was measured with a gamma-ray scintillation counter and compared to that induced by thermal neutrons. A U^{235} fission counter served to compare the fast and thermal neutron flux. From the ratios of gamma-ray counts, the ratios of fission counts, and the known thermal activation cross sections, fast neutron activation cross sections could be calculated. They vary approximately as $1/v$ for Cu, Ag, I, and W and as $1/E$ for V and Mn. For As and Au, the cross sections show a dependence of $1/v$ changing to $1/E$ as the energy increases. A broad plateau is exhibited by Mo and a broad maximum occurs in the energy dependence for In, Ba, Sm, and Dy.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] R. L. Henkel and H. H. Barschall, Phys. Rev. 80, 145 (1950).

B7. Total Neutron Cross Sections of Neon, Argon, Krypton, and Xenon. F. J. VAUGHN, W. I. IMHOF, R. G. JOHNSON, AND M. WALT, *Lockheed Aircraft Corporation.*—The total neutron cross sections of the noble gases neon, argon, krypton, and xenon have been measured for neutron energies from 120 kev to 6.4 Mev by a transmission experiment. The neutrons were produced using the $Li^7(p,n)Be^7$, the $T(p,n)He^3$, and the $D(p,n)He^3$ reactions in the appropriate energy intervals. Protons or deuterons were obtained from Van de Graaff accelerator. The scattering samples consisted of stainless steel tubes, 1 in. in diameter and 12 in. long, filled with gas to pressures ranging from 1200 psi to 2800 psi. For neutrons below about 500 kev, a Li^6I crystal sandwiched between a Lucite moderator and mounted on a photomultiplier was used as a detector. At higher energies a plastic phosphor detector was employed. The measurements are now being extended to the energy region 13 to 19.5 Mev, using neutrons produced in the $T(d,n)He^4$ reaction.

B8. $(\gamma-\gamma)$ Angular Correlation Measurements on Ti^{49}. $(n,\gamma)Ti^{49}$ and $Si^{29}(n,\gamma)Si^{29}$ Reactions. G. MANNING AND G. A. BARTHOLOMEW, *Chalk River Laboratories.*—Two large sodium iodide crystals have been used as detectors to study the angular correlation between cascade γ rays following thermal neutron capture. Correlation measurements have been made between the following pairs of γ rays in the decay of Ti^{49}: 6.75−1.38; 6.41−0.34; and 1.38−0.34 Mev. The results of these measurements confirm the $(1/2-)$ and $(3/2-)$ assignments of Trumpy[1] for the 1.72- and 1.38-Mev levels of Ti^{49}, respectively. If it is assumed that the 0.34-Mev γ ray is an $E2/M1$ mixture and the 1.38-Mev γ ray is pure $E2$ radiation, the observed 0.34−1.38 correlation gives values of 10^{-2} (in phase) or 5 (180° out of phase) for the square of the multipole-mixture parameter for the 0.34-Mev radiation. Correlation measurements have been made between the 3.54- and 4.93-Mev γ rays following neutron capture in Si^{29}. The results are consistent with a spin of 3/2 for the 4.93-Mev level and pure dipole radiation for both γ rays. Proton distributions from the $Si^{29}(dp)Si^{29}$ reaction[2] indicate that the 4.93-Mev level is $(1/2$ or $3/2-)$. The level is therefore $(3/2-)$.

[1] G. Trumpy, Nuclear Phys. 2, 664 (1956).
[2] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) A66, 467 (1953).

B9. Inelastic Scattering of Neutrons from Iron and Lead by Time of Flight.* PABLO OKHUYSEN, *Texas Nuclear Corporation,* AND WALTER E. MILLETT, *The University of Texas.*—The energy distributions of the neutrons emitted at 90° from a beam of 14.9-Mev neutrons incident upon iron and lead scatterers have been obtained using a simplified associated-particle time-of-flight technique. This technique was originated by O'Neill[1] and has been modified in the present experiment. The apparatus will be described and the energy distributions from iron and lead will be presented.

* Work performed under U. S. Air Force Contract.
[1] G. K. O'Neill, Phys. Rev. 95, 1235 (1954).

B10. Inelastic Scattering of Fast Neutrons in Fe and Pb.* IRA L. MORGAN AND J. T. PRUD'HOMME, *Texas Nuclear Corporation.*—A ring-type geometry and a single crystal NaI(Tl) spectrometer has been used to determine the cross sections for various energy gamma rays by inelastic neutron scattering in Fe and Pb at $E_n=1.0$ Mev, 3.5 Mev, 3.8 Mev, 4.1 Mev, 4.4 Mev, 4.6 Mev, and 15.0 Mev. The angular distribution of the gamma ray emitted from the 0.843-Mev level in iron has been determined at $E_n=4.6$ Mev using a cylindrical-type geometry.

* Work performed under U. S. Air Force Contract.

B11. Inelastic Neutron Scattering in Nb^{93}.* N. NATH,† D. M. VAN PATTER, M. A. ROTHMAN, AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Two levels in Nb^{93} at 0.764 and 0.977 Mev have been investigated by us previously,[1] using the gamma rays excited by inelastic neutron scattering. We have since then observed a number of other gamma rays of which the most prominent are as follows: 0.335±0.005, 0.540±0.01, 1.10±0.03, 1.30±0.03, 1.50±0.04, 1.68±0.05, 1.98±0.05 Mev. In coincidence with the gamma rays from the 0.764-Mev level are seen 0.335±0.005 and 0.540±0.01 Mev. In coincidence with the gamma rays from the 0.977 levels are seen 0.310±0.02, 0.380±0.02, 0.530±0.02, 0.700 ±0.03 Mev. This is consistent with the following level scheme: 0.03 (known from radioactivity), 0.764±0.008, 0.977±0.01, 1.10±0.02, 1.30±0.02, 1.50±0.04, 1.68±0.05, and 1.98±0.05 Mev.

* Assisted by the U. S. Atomic Energy Commission.
† On leave of absence from the University of Delhi, India.
[1] Rothman, Van Patter, Dubey, Porter, and Mandeville, Phys. Rev. 107, 155 (1957).

THURSDAY MORNING AT 10:00

Sheraton-Park, Continental Room

(N. BLOEMBERGEN presiding)

Nuclear Magnetic Resonance

BA1. Nuclear Resonance Experiments on Solid Hydrogen at High Pressures.* WILLIAM D. MCCORMICK AND WILLIAM M. FAIRBANK, *Duke University.*—Nuclear resonance experiments have been carried out on solid hydrogen at pressures up to 5000 atmos. The present experiments were stimulated by a suggestion of F. London[1] that hydrogen molecules would become oriented at sufficiently high pressures resulting in a decrease, perhaps even to zero, of the energy difference between the lowest level of the $J=1$ state (orthohydrogen) and the $J=0$ state (parahydrogen). At 4.2°K the shape and amplitude of the nuclear resonance signal remains approximately constant as the pressure is increased to 5000 atmos. The ortho-para conversion rate, as measured by the rate of change of the amplitude of the resonance line, remains small up to 5000 atmos pressure. At sufficiently low temperatures magnetic interactions cause a fine structure in the resonance line of the solid. At low pressures this appears below 1.5°K as first observed by Hatton and Rollin and subsequently by Reif and Purcell who provided a more detailed explanation of the line shapes. We have observed that the temperature at which the fine structure appears increases with increasing pressure.

* This work supported by the Office of Ordnance Research, Department of the Army.

[1] F. London, Phys. Rev. **102**, 168 (1956).

BA2. Proton Spin Relaxation in Pure Water. R. J. S. BROWN, *California Research Corporation.*—Accurate proton spin relaxation time measurements were made for pure water at 40 temperatures from −10° to 104°C. High-quality multiply distilled water was vacuum boiled, vacuum distilled, and sealed in Pyrex. T_1 was unchanged over several months. T_1 at 2 gauss was determined by polarizing at 1500 gauss, allowing times for relaxation at 2 gauss, and observing free precession in the earth's field. T_1 was also observed at 1500 gauss by varying polarizing periods at −10°, 0°, 20°, and 100°C. The low- and high-field results were the same. The errors in the low-field relaxation times, including temperature errors, are thought to be about 1% or less, except below 0° and above 85°C, where the errors may be about 1.5%. Wall effects in the 300-cc sample should be negligible. The high-field T_1 at −10°C was probably not in error more than 2% and agreed with the low-field value within 0.3%. At 2 gauss $\log_{10}T_1=0.618x_A^2+2.800x_A+2.986-(944x_A+710)T^{-1}$ where T_1 is in seconds, T is °K, and $x_A=[1+\exp(13.54-3700/T)]^{-1}$. This curve falls about 2% (for T_1) below measured values above 95°C and 1% below between 0° and 10°C. The product $\eta T_1(1000/T)^{0.574}$ is within 1% of 6.36 for nearly all points between 0° and 85°C and is 2% lower above 90° and 3% lower below −5°C, where η is viscosity[1] in centipoise.

[1] Dorsey, *Properties of Ordinary Water Substance* (Reinhold Publishing Corporation, New York, 1940), Tables 82 and 85.

BA3. Temperature Dependence of T_1 for Na^{23} in NaCl. O. KRAUS, *National Bureau of Standards.*—Using pulsed nuclear induction, we have measured the spin-lattice relaxation time of sodium nuclei in sodium chloride. Measurements were made on a single crystal of sodium chloride at a frequency of 8.57 mc/sec, and relaxation times were determined for the temperature interval between 300°K and 130°K. Typical values of T_1 are 7.1 sec at 298°K and 32 sec at 174°K. Within the temperature range of the measurements, the temperature dependence of the spin-lattice relaxation time agrees with the quadrupolar relaxation theory of Van Kranendonk.[1]

[1] J. Van Kranendonk, Physica **20**, 781 (1954).

BA4. Nuclear Spin-Lattice Relaxation in KH_2PO_4.* JOHN L. BJORKSTAM AND EDWIN A. UEHLING, *University of Washington.*—Studies of the relaxation time in the deuterated form of potassium dihydrogen phosphate[1] have suggested a re-examination of the relaxation in the nondeuterated form. Measurements made by Newman[2] on the proton relaxation were interpreted by him in terms of a random jump process. We find in fact that the relaxation in his crystals, and presumably in ours, is governed by a process of energy transfer to paramagnetic impurity ions first proposed by Bloembergen.[3] Whereas Newman obtained relaxation times for protons equal to 1.6 sec and 0.25 sec, respectively, for crystals of KH_2PO_4 and KH_2AsO_4 we obtain times equal to 30 sec and 85 sec respectively for our particular crystals under the same conditions of temperature and frequency. The phosphorus relaxation time in KH_2PO_4, and in the deuterated form, is longer. The proton relaxation shows a very striking frequency dependence. In KH_2AsO_4 T_1 varies linearly from 32 sec at 10 Mc/sec to 112 sec at 40 Mc/sec. An interpretation of these results will be given.

* Crystals kindly supplied by the Clevite Research Center.
[1] John L. Bjorkstam and Edwin A. Uehling, Bull. Am. Phys. Soc. Ser. II, **2**, 383 (1957).
[2] Roger Newman, J. Chem. Phys. **18**, 669 (1950).
[3] N. Bloembergen, Physica **15**, 386 (1949).

BA5. NMR Spectra of Alkali Halide Solutions.* DANIEL D. ELLEMAN, L. CARLTON BROWN, AND DUDLEY WILLIAMS, *The Ohio State University.*—Resonances for Li^7, Na^{23}, Rb^{85}, Rb^{87}, Cs^{133}, Cl^{35}, Br^{79}, Br^{81}, and I^{127} have been studied in aqueous solutions of alkali halides. Line widths and frequency shifts were measured as functions of concentration. The widths of the broader lines have been interpreted qualitatively in terms of nuclear quadrupole effects. The widths of certain resonance lines in D_2O solutions are not noticeably different from those in H_2O solutions. Addition of ethanol is found to increase the widths of some lines. The ratio of the line widths of Br^{79} to Br^{81} extrapolated to zero concentration is proportional to the square of the ratio of the nuclear quadrupole moments, an observation in agreement with Pound's results for a single dilute solution. The shift in frequency with concentration is interpreted qualitatively in terms of the ionic environment.

* Supported in part by Air Force Office of Scientific Research (ARDC).

BA6. Chemical Shifts of N^{14} in the NMR Spectra of Nitrates, Nitrites, and Nitro-Compounds.* BERNHARD M. SCHMIDT, L. CARLTON BROWN, AND DUDLEY WILLIAMS, *The Ohio State University.*—The nuclear magnetic resonances of N^{14} in the nitrate groups $LiNO_3$, $NaNO_3$, KNO_3, $AgNO_3$, $Ag(NH_3)_2NO_3$, $Zn(NO_3)_2$, $Pb(NO_3)_2$, $Cd(NO_3)_2$, $UO_2(NO_3)_2$, and $Al(NO_3)_3$ have a zero chemical shift with respect to the N^{14} peak in the nitrate group of NH_4NO_3; the line widths of these resonances are the same. The N^{14} peak in HNO_3 is of comparable width but has a large positive shift that is concentration dependent; this observation is in agreement with earlier studies. The N^{14} peak in the paramagnetic salt $Cu(NO_3)_2$ has a large concentration-dependent positive shift. The

organic compounds containing NO_2 groups showed positive shifts and line widths approximately 4 times that of the normal nitrates. The N^{14} resonance in $NaNO_2$ is 20 times the width of the normal nitrate resonance and has a large negative shift. The results are discussed.

* Supported in part by the Office of Naval Research.

BA7. Pressure Dependence of the Pure Quadrupole Resonance Frequency in Metallic Gallium.* T. KUSHIDA AND G. B. BENEDEK, *Harvard University.*—We have studied the pure quadrupole resonance of the Ga^{69} nucleus in metallic gallium[1] under hydrostatic pressure in the range 1 to 8000 kg/cm² at 0°C, −29.8°C, −75°C. It was found that ν varies linearly with the pressure at all temperatures. $(d\nu/dP)_T$ is 16.1×10^{-3} kc/hg/cm², 15.8×10^{-3} kc/hg/cm², 15.4×10^{-3} kc/hg/cm² at 0°, −29.8°, and −75°C, respectively. No appreciable change was found in the line width as the pressure was increased. In view of the anisotropy in the thermal expansion,[2] the probable anisotropy of the compressibility and the absence of knowledge as to the size of the asymmetry parameter, a detailed analysis of these results cannot now be given. However, a semiquantiative analysis of the results in terms of the volume dependence of the effective field gradient tensor components will be offered. This analysis will be applied to a discussion of the possible sources of the field gradient.

* Supported by Joint Armed Services Contract.
[1] Knight, Hewitt, and Pomerantz, Phys. Rev. **104**, 271 (1956).
[2] R. W. Powell, Proc. Roy. Soc. (London) **A209**, 525 (1951).

BA8. N^{14} Pure Quadrupole Resonances in Malononitrile.* P. J. BRAY AND P. A. CASABELLA,† *Brown University.*—Two N^{14} pure quadrupole resonances have been observed in $(CN)_2CH_2$ at 77°K, using a Pound-Watkins type recording spectrometer. Preliminary measurements show their frequencies to be 2.86 Mcps and 3.01. The resonances are accompanied by a set of negative wings, due to the combination of Zeeman modulation and phase sensitive detection. The shape of these wings clearly shows that the two resonances are due to a single value of the quadrupole coupling constant, eQq, and a nonzero value for the electric field gradient asymmetry parameter η.[1] The frequencies of the observed resonances indicate that $eqQ=3.9$ Mcps and $\eta=7.7\%$. For $I=1$, Zeeman modulation becomes less effective as η increases, as the present case demonstrates. 7.7% is the largest value of η observed to date for N^{14}. Even this relatively small value results in very narrow negative wings, and a weak resonance signal. It is probable that for values of η much larger than the present case, a N^{14} resonance would not be observable unless a Zeeman field considerably larger than the 25 gauss used in this experiment were employed.

* Work supported by a Frederick Gardner Cottrell Grant from the Research Corporation.
† Supported by an Ohio Oil Company Fellowship.
[1] P. A. Casabella and P. J. Bray, J. Chem. Phys. (to be published).

BA9. Cl^{35} Pure Quadrupole Resonances in Pyrimidines.* H. O. HOOPER AND P. J. BRAY, *Brown University.*—Cl^{35} pure quadrupole resonances have been measured in nine pyrimidines. In five cases a chlorine is bonded to the 2-position carbon located between the two nitrogens in the six-membered ring. Previous work[1] has indicated a decrease in the frequency of a halogen bonded to a carbon adjacent to one ring nitrogen. This effect, presumably arising from increased double bonding in such carbon-halogen bonds, is apparent in pyrimidine but is unexpectedly less at the 2 position than at the 4 and 6 positions (carbon atom adjacent to only one ring nitrogen). The results of various molecular orbital charge distribution calculations have been compared with the observed halogen frequencies. These distributions depend primarily on assumptions concerning the nitrogen Coulomb integral and its perturbation of the Coulomb integrals of the ring carbons. The best frequency-charge density correlation is obtained with a method[2] entailing a very moderate effect of the nitrogen on only the adjacent carbon Coulomb integrals. Even this scheme barely equilibrates the double bonding at the 2 and 4, 6 positions and is not fully satisfactory.

* Work supported by a grant from the National Science Foundation.
[1] Bray, Moskowitz, Hooper, Barnes, and Segel, J. Chem. Phys. **28**, 99 (1958).
[2] H. H. Jaffe, J. Chem. Phys. **20**, 1554 (1952).

BA10. Electron Distribution in Some Group III Halides.* P. A. CASABELLA† AND P. J. BRAY, *Brown University.*—The quadrupole coupling constants of all the atoms in the structure of a number of group III halides are known.[1–4] For these cases it has been possible to determine the direction and electron population of all the bonding orbitals of the molecule using only the quadrupole coupling data. The results obtained in this manner agree favorably with x-ray data, where available. The compounds for which a complete set of data is available at $AlBr_3$, $GaBr_3$, GaI_3, InI_3. In AlI_3 the I^{127} resonances are known, and one of the Al^{27} resonances has been found at 3.3 Mcps. The evidence indicates that this is probably the $\frac{5}{2}\rightarrow\frac{3}{2}$ transition, and a search is underway for the $\frac{3}{2}\rightarrow\frac{1}{2}$ line.

* Work supported by a Frederick Gardner Cottrell Grant from the Research Corporation.
† Supported by an Ohio Oil Company Fellowship.
[1] R. G. Barnes and S. L. Segel, J. Chem. Phys. **25**, 180 (1956).
[2] S. L. Segel and R. G. Barnes, J. Chem. Phys. **25**, 578 (1956).
[3] Barnes, Segel, Bray, and Casabella, J. Chem. Phys. **26**, 1345, (1957).
[4] P. A. Casabella and P. J. Bray, Bull. Am. Phys. Soc. Ser. II, **2**, 225 (1957).

THURSDAY MORNING AT 9:45

Sheraton-Park, Caribar-Mural Room

(E. T. BOOTH presiding)

Accelerators I

C1. Orbit Theory of an A. G. Accelerator with Arbitrary Magnetic Field.* G. PARZEN,† *Midwestern Universities Research Association.*—The problem of finding the motion of a particle in a circular accelerator having an arbitrary magnetic field has been investigated. An approximate and relatively simple solution of the equations of motion has been found. The approximations made are such that for presently considered A. G. accelerators, the results may be expected to be accurate to within 15%. Expressions for the equilibrium orbit, the tune, and the stability limits for a machine having an arbitrary magnetic field will be presented. The approximations made will also be discussed.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Notre Dame.

C2. Injection Considerations for High-Energy Two-Way Colliding Beam FFAG Accelerators. LAWRENCE W. JONES,* FRED E. MILLS, KEITH R. SYMON, AND KENT M. TER-

WILLIGER,* *Midwestern Universities Research Association.*—It is shown that a 50-Mev proton linear accelerator of the Brookhaven design[1] will have a sufficiently high phase space density to achieve injection of 0.3 amp or 2×10^{13} protons per injector pulse into a 180-meter radius 15-Bev Ohkawa-type[2] FFAG accelerator. Multiple turn injection using a programmed magnetic bump could inject 60 turns into a reasonable injection aperture (±15 cm). The space charge limit is computed including alternating gradient effects, using a Mathieu equation representation, where space-charge terms arising from the azimuthal variation of beam dimensions are added to magnetic field terms. The detuning of oscillations calculated in this way is somewhat less than that obtained using a uniform cylindrical charge distribution. The azimuthal shrinkage of the beam when accelerating rf is applied will increase the charge density and decrease the space charge limit correspondingly. This effect determines the rf voltage and modulation schedule for a beam with maximum density in rf phase space.

* University of Michigan.
[1] Lloyd Smith, Brookhaven Report LSS-3 (unpublished).
[2] T. Ohkawa and L. Jones, Bull. Am. Phys. Soc. Ser. II, 2, 11 (1957).

C3. Stacked Circulating Currents in Colliding Beam FFAG Accelerators. KENT M. TERWILLIGER,* LAWRENCE W. JONES,* AND KEITH R. SYMON, *Midwestern Universities Research Association.*—In a scaling FFAG accelerator the number of injected pulses which can be spatially superposed is limited by the energy spread contained in each pulse. This is due to the phase displacing effect of the accelerating rf voltage. An expression for the stacked beam current density, including rf displacement and space-charge effects, will be presented. For a two-way 15-Bev FFAG accelerator, a proton current density of 50 amp/cm^2 appears quite feasible. Two such intersecting 15-Bev proton beams would produce approximately 10^5 nuclear p-p interactions per cm^3 per sec (assuming a 25 mb cross section). With 1000 total stacked amperes, there would be about 10^6 interactions/cm/sec or about 10^8 interactions per second over a meter of collision region. At 10^{-8} mm Hg the p-p interaction rate per unit volume equals that of the protons with the residual gas nucleons. At this pressure the beam lifetime due to nuclear interactions and gas scattering is long enough to build up the required number of pulses. Other factors which might affect the stored beam appear controllable. These are: detuning by trapped ionization electrons, rf excitation of betatron oscillations, and detuning due to beam intersections.

* University of Michigan.

C4. Experimental and Computer Studies of the Effect of Pulsed Constant Frequency Oscillators on Stacked Beams in FFAG Accelerators.* C. H. PRUETT AND C. G. LILLIEQUIST, *Midwestern Universities Research Association* (introduced by K. R. Symon).—Computer studies with an IBM 704 and experiments with a small radial sector FFAG accelerator have produced results consistent with predictions of the rf theory of Symon and Sessler[1] concerning pickup and redistribution of particles in a stacked beam by a constant frequency rf voltage. The computer experiments investigated this problem relative to the turn-on rate of the voltage. For particles differing by more than one-quarter of the energy width of the "bucket" (phase stable region), turn-on in one-half of a phase oscillation period seems to be reasonably adiabatic. However, particles with initial energy nearer the bucket center require slower turn-on rates. The small electron accelerator has been used to investigate the prediction that half the particles stacked at an energy E can be transferred to a stack at an energy $E+\Delta E$ by an adiabatic rf pulse with a frequency corresponding to the energy $E+(\Delta E/2)$. The average energy width of the bucket must be greater than ΔE. In the accelerator, electrons have been transferred from one stack to another about 15 kev higher with a 60 v rf pulse on the accelerating gap.

* Supported by the U. S. Atomic Energy Commission and the National Science Foundation.
[1] K. R. Symon and A. M. Sessler, *Proceedings of the CERN Symposium on High Energy Accelerators and Pion Physics* (CERN, Geneva, 1956), Vol. I, p. 44.

C5. Study on the Effects of Imperfections in an FFAG Spiral Sector Accelerstor.* F. L. PETERSON AND W. A. WALLENMEYER, *Midwestern Universities Research Association.*—Experiments have been carried out to determine the effect of imperfections and misalignments on the operation of the FFAG spiral sector model. Computer calculations have indicated that this model would be relatively insensitive to most of these and the experimental results confirm this. The imperfections introduced were as follows. (1) The magnetic field was decreased by 10% in one sector. (2) The field index k was increased in one sector. (3) A sector was moved vertically up or down. (4) A sector was twisted about a point on its inner radius. These imperfections were introduced consecutively in each of the six sectors of the model. Measurements were made, with the aid of various probes, of the frequency and amplitude of the betatron oscillations and also of the shape and position of the equilibrium orbit. The results of these experiments will be described and compared with the theoretical results.

* Supported by the U. S. Atomic Energy Commission and the National Science Foundation.

C6. Motion near the Intersection of Two Nonlinear Coupling Resonances in an FFAG Accelerator.* HOMER K. MEIER,† *Midwestern Universities Research Association* (introduced by K. R. Symon).—An analytic theory based on a Moser[1] type canonical transformation has been compared with the motion computed on MURA's IBM 704 computer. The study was made near the intersection of the $\nu_x+2\nu_y=1$ and $\nu_x-2\nu_y=0$ resonances. The effects of both resonant lines are considered simultaneously. The equations of motion used result in simple harmonic motion except for a nonlinear discontinuity in the particle's momentum once a sector. This has made possible the use of an algebraic transformation to take the particle through a sector. The resultant speed of the calculation has made it possible to follow the motion for a very long time. The results are in agreement with what the theory is capable of predicting for simultaneous treatment of the lines, and show that for small amplitudes the motion remains stable for at least 10^6 sectors.

* Supported by the U. S. Atomic Energy Commission and the National Science Foundation.
† Now at the University of Wisconsin.
[1] J. Moser, Nachr. Akad. Wiss. Göttingen Math.-Physik Kl. 1955, No. 6.

C7. Observation of Space-Charge Beam Instabilities in the Spiral Sector Model FFAG Electron Accelerator.* F. E. MILLS AND D. S. ROISELAND, *Midwestern Universities Research Association.*—A beam of electrons held together by external focusing fields will trap ions produced by electron bombardment of the residual gas and will tend toward electrical neutrality. The plasma thus formed will influence the focal properties of the electron beam. In the case of beams in cyclic accelerators resonant phenomena can occur which produce instabilities not present with electrons alone. Plasma effects of this kind were observed in the spiral sector model electron accelerator. Electrons were injected into the accelerator for a time long compared to the time required to accelerate them to full energy, producing a sheet of charge extending from the injection radius out to the target radius. Instabilities were observed which corresponded to the destruction of this entire sheet of charge in a time small compared to the acceleration time. Since electrons were being continuously injected and accelerated, the sheet of charge could

re-establish itself and then undergo another instability. Radio-frequency signals apparently corresponding to plasma oscillations were observed before and during the instabilities of the beam. The introduction of electric fields to sweep away the ions was partially successful in stabilizing the electron beam.

* Supported by the U. S. Atomic Energy Commission.

C8. Magnet Steel for the Brookhaven Alternating Gradient Synchrotron.* R. A. BETH AND C. LASKY, *Brookhaven National Laboratory.*—Magnet production has started for the 25–30 Bev Brookhaven A.G. Proton Synchrotron scheduled for completion in 1960. Although a magnetically suitable low-carbon plate could be made, an 0.031-in. gauge M-36 electrical sheet, 1.80% Si, 0.03% C, was chosen because it is felt that greater accuracy and uniformity of gap contour can be attained by punching sheet than by milling plate for the 240 magnets. About 4000 tons of electric furnace steel, cold reduced, annealed, and cut to 33½ in. × 39½ in. stamping blanks will be required. The sheet flatness achieved by the Allegheny Ludlum Steel Corporation is essential for the mechanical accuracy of the magnets. Magnetic measurements show the following average properties and standard deviations for 118 five-ton batches of the first class before and after aging (5 days at 150°C): coercive force in oersteds = $0.775 \pm 10\%$; $1.26 \pm 12.5\%$; low field permeability at 100 gauss = $737 \pm 12\%$; $280 \pm 16\%$. The high-field permeability at 120 oersteds is 149 and does not age. For magnetic uniformity the blanks for each of the three classes of magnets are shuffled in a carefully planned way before punching and stacking. Magnetic uniformity around the half-mile ring will be essential for proper injection conditions at 120 gauss on the orbit.

* Work carried out under contract with U. S. Atomic Energy Commission.

C9. Monte Carlo Calculations of the Shielding of the Princeton-Pennsylvania 3-Bev Proton Synchrotron.* C. J. TSAO, R. B. CURTIS,† B. K. HARRISON, AND G. K. O'NEILL, *Princeton University.*—Monte Carlo calculations have been made on an IBM 704 for the shielding of the Princeton-Pennsylvania 3-Bev proton synchrotron. The structure consists of a steel ring magnet inside a totally enclosing shield. A cascade starts with a 3-Bev proton colliding with a target in the center of the magnetic gap. The particles produced in collisions are followed until they leave the shield or when their energy at a collision is less than 15 Mev. Only neutrons and protons are considered; they move in straight lines between collisions except for protons in the magnetic gap. Proton ionization losses are included in the calculation. The input collision data, i.e., the average number and type of particles produced, their energy spectrum and angular distribution, and the excitation of the residual nuclei are taken from the work of Metropolis *et al.*[1] A splitting technique is used to improve statistics on the outgoing particles. Energy and position distributions on the inner and outer walls of the shield have been obtained.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at the Institute for Advanced Study.
[1] Metropolis, Bivins, Storm, Turkevich, Miller, and Friedlander, Phys. Rev. (to be published).

C10. Concentric Storage Rings.* E. J. WOODS AND G. K. O'NEILL, *Princeton University.*—An alternative geometry for storage rings,[1] having advantages of convenience and smaller size, has been developed.[2] By alternating large and small radii of curvature, circulating beams in two concentric guide field rings would be made to cross at several field-free points. The size of the device would be larger than that of a synchrotron of the same energy and peak field by only 20%. In the case of the Princeton-Pennsylvania 3-Bev proton synchrotron pulsed magnetic inflection and beam stacking would produce circulating beams of ~3 amperes, assuming 3×10^{10} protons/pulse in the synchrotron and conservative estimates for phase density losses. In each of six interaction regions, there would then be several hundred strange-particle producing interactions per second. A vacuum chamber able to be baked out in place would be used; the interaction rate in the residual gas would be roughly equal to the total rate of beam-on-beam interactions. Computer calculations on alternating-gradient cell structures will be presented.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] G. K. O'Neill, Phys. Rev. **102**, 1418 (1956).
[2] Princeton-Pennsylvania Accelerator Project, Internal Report, GKO'N-11.

C11. Drift Tube Driver Unit for High-Repetition Rate Synchrotrons.* MICHAEL E. SZEKELY, *Princeton University* (introduced by G. K. O'Neill).—In a ferrite loaded tunable rf system ferrite biasing power increases sharply with repetition rate. Such a system is being used on the Princeton-Penn Synchrotron, but an alternative was studied. Mathematic analysis of a modified butterfly tank circuit shows that by appropriately shaping the stator and rotor elements, the time-frequency curve of the tuner rotating at the pulse rate can be closely adjusted to that of a synchrotron with sinusoidally varying gap field. For a frequency range of 2.5–30.5 mc a capacity swing of 27:1 and in inductance swing of 2:1 can be accomplished. By partly loading the stator with biased ferrite rings, the inductance ratio extends to 6:1. Two multi-turn sets of biasing coils for slow acting μ control and for high speed fine frequency trimming respectively promises the use of low power bias supplies. The radio-frequency power and tube requirements are analyzed with the aid of simplified formulas for the ferrite losses and Q, giving about 5 kw rf and 5 kw bias power for each of the four accelerating stations at 38 kv peak accelerating voltage on each 4-ft drift-tube.

* Work supported by the U. S. Atomic Energy Commission and the Higgins Trust Fund.

C12. Energy Control of a 25-Mev Betatron.* K. N. GELLER, J. HALPERN, E. G. MUIRHEAD, AND P. F. YERGIN, *University of Pennsylvania.*—To obtain precise information concerning photonuclear reactions, energy stability of the bremsstrahlung tip is often required to be better than ±10 kev over an extended period. To this end a new energy control system has been designed. Integration of the voltage induced in a small pickup coil situated at the electron donut serves as the analog of the orbit flux density. Expansion of the electron orbit occurs when this analog voltage exceeds a preselected discriminator level. For increased energy resolution a faster method of expansion using a quadrupole sector coil[1] is employed. The x-ray pulse has a full width at half-intensity of 0.3 μsec. To maintain a fixed relation between orbit flux density and the voltage analog, the latter is clamped near ground for about 1200 μsec before the field passes through zero. At this time, a zero-field trigger occurs which releases the clamp and allows the reference voltage to rise. Short term stability of better than ±4 kev has been achieved. A drift of about 10 kev over a 10-hour interval is present. The over-all long term stability for a typical 5-week interval is 15 kev. A preliminary calibration based on (γ,n) thresholds for D, Be^{9}, Bi^{209}, Pb^{207}, Pb^{208}, Cu^{63}, and P^{31} is linear on a momentum *versus* "helipot" setting plot. The calibration is known to about 50 kev. The apparent thresholds for O^{16}, and B^{10} fall off this calibration line by approximately 200 kev.

* Supported in part by the Air Research Development Command and by the U. S. Office of Naval Research.
[1] C. L. Hammer and A. J. Bureau, Rev. Sci. Instr. **26**, 594, 598 (1955).

THURSDAY MORNING AT 9:45

Shoreham, Main Ballroom

(D. A. BROMLEY presiding)

Invited Papers in Nuclear Physics

CA1. The Stripping and Direct Interaction in Nuclear Reactions. W. M. MACDONALD, *University of Maryland.* (30 min.)

CA2. Absolute Determinations of Nuclear Reaction Energies. R. C. BONDELID, *U. S. Naval Research Laboratory.* (30 min.)

CA3. Proton-Capture Reactions in Medium-Weight Nuclides. J. W. BUTLER, *U. S. Naval Research Laboratory.* (30 min.)

CA4. Proton-Proton Scattering Experiments. L. H. JOHNSTON, *University of Minnesota.* (30 min.)

THURSDAY MORNING AT 9:45

NBS, Materials Testing Building

(C. N. YANG presiding)

Theoretical Physics I (Including Field Theory)

D1. Classical Limit of Vector Coupling and Racah Coefficients. E. P. WIGNER, *Princeton University.*—The square of the vector coupling coefficient gives the quantum theoretical probability that the sum of two vectors has a given length if the components of these two vectors in a certain direction are given fixed values. If one adds three vectors j_1, j_2, j_3 to form a resultant J, one can keep the length j_{12} of the sum of the first two vectors constant and ask for the probability that the sum of the last two vectors, j_{23}, have a given length. The square of the Racah coefficient gives the quantum theoretical value of this probability; it depends on the lengths of six vectors: j_1, j_{12}, j_2, j_3, j_{23}, J. In the limiting case of large vectors the quantum theoretical probability can be approximated by the JWKB method. This has been done by Racah himself, by Opechowski, Edmonds, and, perhaps in most detail, by Brussard and Tolhoek. The actual classical limit for the square of the Racah coefficient is the reciprocal of 24π times the volume of the tetrahedron spanned by the six vectors on which the coefficient depends. This also explains the symmetrical dependence of the Racah coefficient on the lengths of these vectors. The square of the vector coupling coefficients has a similar geometric interpretation in the classical limit.

D2. Design of a Quantum Electrodynamics Limit Experiment.* G. K. O'NEILL, *Princeton University.*—Several experiments relating to a possible breakdown of quantum electrodynamics at high energies (small distances) have been reported. Their ultimate limits appear to be 0.3×10^{-13} cm or larger. To settle questions on nucleon size, the n-p mass differences and a possible "fundamental length" for electromagnetic interactions, one needs a more sensitive probe. An experimental design for electron-electron scattering at 500 Mev (center of mass), sensitive to 0.6×10^{-14} cm, has been studied in detail. 500-Mev electrons would be inflected into two storage rings of 1-m radius, totaling 20 tons in weight, and the resulting circulating beams allowed to collide. Classical synchrotron radiation would damp the beams to small size (0.1 cm³) in 1 msec. Fixed frequency rf cavities to supply 5 kev/turn of radiation losses are needed. Cavity voltage of 40 kv would be required to reduce quantum fluctuation beam losses to tolerable limits. A clean metal vacuum system designed to be baked out would permit long beam lifetime and low background. Ring currents of 1 amp are calculated to be stable if made to cross at a small angle, and would give 10 scatterings/sec above 30°.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

D3. Proof of Dispersion Relations in Field Theory. RICHARD PRANGE AND ABRAHAM KLEIN,* *University of Pennsylvania.*—Recent proofs of dispersion relations for pion-nucleon scattering[1] employ the device of continuing the amplitude with respect to the square of the pion mass. Dispersion relations are established first for negative values of this parameter. The passage back to the physical value is then rigorously justified. We have developed an alternative method which initially proceeds by keeping part of the energy dependence fixed. In a manner formally analogous to the proof for the forward scattering of light, the amplitude is then shown to satisfy a dispersion relation in the remaining energy dependence. The relation itself is unconventional; however, in that the absorptive part refers solely (except for one point) to the nonphysical region. In order to convert to the more usual relation, the behavior of the amplitude as a function of the hitherto unused energy dependence has been studied. So far the proof has been completed only for the limit of infinite nucleon mass.

* Supported in part by the Air Research and Development Command.

[1] Bremermann, Oehme, and Taylor (to be published); Bogohubov, Medvedev, and Polivanov (lecture notes).

D4. Quantization Process for Massless Particles.* C. L. HAMMER AND R. H. GOOD, JR., *Iowa State College.*—Recently a wave equation for massless particles of spin s was proposed[1] in which the Hamiltonian $H=(c/s)\mathbf{P}\cdot\mathbf{s}$. The quantization process for this theory can be carried out in a straightforward way, using the coefficients in an expansion on plane waves. It is found that the spinor components of a boson/fermion field with integer/half-integer spin commute/anticommute off the light cone, whereas the spinor components of a boson/fermion field with half-integer/integer spin do not. Also the different statistics lead to different expressions for the operators when they are written in terms of the wave function. For example, with Fermi-Dirac statics the quantized Hamiltonian corresponds to the expected value of the unquantized

Hamiltonian, whereas with Bose-Einstein it corresponds to the expected value of the unquantized energy operator.

* This research was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
[1] C. L. Hammer and R. H. Good, Jr., Phys. Rev. **108**, 882 (1957).

D5. Enumeration of True Observables in Gauge Invariant Theories. JAMES L. ANDERSON, *Stevens Institute of Technology.*—Gauge invariant theories are those which are invariant with respect to a group of transformations whose elements are determined by n space-time functions. As a consequence of this type of invariance, only certain dynamical variables have the property that their evolution in time is uniquely governed by the field equations. Such variables will be referred to as true observables. These true observables can serve as "coordinates" for our system. The number needed however, will in general be less than N, the original number of field variables. The exact number needed can be derived from arguments of invariance. In all cases, n linear combinations of the field equations will be free of second time derivatives of the original field variables. This means that at most only $N-n$ "coordinates" are needed to describe our system. An additional number of superfluous variables results if the transformation law contains time derivatives of the functions which specify the group. In electrodynamics and gravitation theory, the number of coordinates needed is $N-2n=2$ in both cases. The fourleg representation of gravity also requires just 2 "coordinates" although the argument is somewhat different in this case.

D6. Stationary Damping Theory.* C. ALDEN MEAD, *Brookhaven National Laboratory.*—A general formalism is developed for finding the stationary states of a system in which damping phenomena can occur. This leads to a simple criterion for deciding whether there exists a stationary state of the perturbed system which converges to a given unperturbed state in the limit of zero interaction. Two simple examples are briefly discussed: (1) the Lee model with a cutoff and an unstable V particle; and (2) the complex refractive index of an ideal gas. In the latter case, a canonical transformation due to Arnous and Bleuler[1] is made use of, and a formally exact solution is then obtained by this method.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] E. Arnous and K. Bleuler, Helv. Phys. Acta **25**, 581 (1952).

D7. Two-Component Fermion Theory.* LAURIE M. BROWN, *Northwestern University.*—Among several recent proposals of a universal V, A Fermi interaction, one[1] has been motivated by a consideration of the relativistic generalization of Pauli's equation for the electron. This equation has been examined with respect to electromagnetic interactions. While its predictions are identical with those of the Dirac theory, it is more restrictive in several useful ways: it does not allow the inclusion of an intrinsic anomalous moment of Pauli type; it is CP invariant but not C and P invariant (though electromagnetic *effects* have the full invariance in consequence of the velocity dependence of the interaction); it leads to *simple* interaction forms only of the vector and axial vector types, even for parity conserving interactions. Calculational techniques are developed in a more convenient form than have been presented for the Dirac theory: no "energy" projection operators are required in traces; only polarization vectors and momentum transfer vectors appear in traces; the interaction falls naturally into a "charge" and a "spin" interaction having different energy dependences, permitting a simple physical interpretation.

* Research supported in part by National Science Foundation.
[1] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).

D8. Invariant Transformation and Field Theories. IRWIN GOLDBERG, *Brookhaven National Laboratories.*—We have studied the infinitesimal transformation of a classical field in the Lagrangian formalism. In particular, the group of local transformations which leave the Lagrangian invariant have been examined. The generators are those quantities which are divergenceless modulo the field equations. The change in one generator under a transformation is the generator of the commutator transformations. This property is also possessed by the infinitesimal unitary transformations in Hilbert space and, therefore, the classical group may prove an aid in the quantization of some nonlinear fields.

D9. Wave Optical Approximation in 1-Bev p-p Scattering. P. SCHWED, *RIAS, Inc.*—In earlier work,[1] the experimental results for p-p scattering at 1 Bev were satisfactorily represented both by a "black sphere" wave optical model with a scattering function of the form $[J_1(3.1\sin\vartheta)/\sin\vartheta]$ and by a 1-parameter set of complex phase shifts. However, the set of imaginary infinite phase shifts appropriate to a black sphere was shown inconsistent with the data; it further was shown subsequently[2] that the J_1 expression given above has an inadmissibly large S-wave part corresponding to particle creation. This led to the present investigation of the validity of this form of the scattering function. Introduction of an obliquity factor into the J_1 expression and subsequent antisymmetrization of the resulting scattering function lead to a result which is still in substantial agreement with experiment but no longer violates particle conservation. By means of a general phase shift analysis of the original J_1 scattering function, the relation between it, and the correct expression for a black sphere is obtained, and the specific way in which the two approach for large kR is demonstrated. For 1-Bev p-p scattering, the S-wave phase shift is π rather than $i\infty$.

[1] W. Rarita, Phys. Rev. **104**, 221 (1956).
[2] W. Rarita and P. Schwed, Bull. Am. Phys. Soc. Ser. II, **2**, 176 (1957).

D10. Bounds on Scattering Phases for a Compound System. LARRY SPRUCH AND LEONARD ROSENBERG, *New York University.*—An extension has been sought for the scattering by a compound system of the method of T. Kato for finding bounds on scattering phases for a static potential. In particular, s-wave scattering of positrons from atomic hydrogen has been investigated. The kinetic energy of the incident positron is taken to be less than the binding energy of positronium to eliminate pick-up or excitation. The possibility of exchange, although absent in the real problem, exists in the associated eigenvalue problem. For this reason the electron is imagined to be enclosed in a box, the size of which, in the case of zero energy scattering, may be made arbitrarily large. Pick-up in the associated eigenvalue problem is thereby also eliminated. By assuming that the positron is free when it is outside a certain region, which in the zero energy case may be made infinite in extent, it is shown that the variational expression for the phase shift, which ignores second order errors, provides a lower bound. Calculations were made for zero energy and 3.5 electron volts.

D11. Electron Capture by Protons in Hydrogen.* T. F. TUAN AND E. GERJUOY, *University of Pittsburgh.*—The theory of electron capture by protons incident on atomic hydrogen has been discussed by Brinkman and Kramers, and others. Comparison of theory and experiment consistently has been based on the assumption that in charge transfer one H_2 molecule is equivalent to two isolated H atoms. We have evaluated in first Born approximation the capture cross section σ stemming from the interaction between the incident proton and the H_2 molecular electrons. Comparing our σ with σ_{BK} of Brinkman and Kramers, we see that charge transfer in H_2 bears no simple relationship to charge transfer in atomic hydrogen. In particular (i) there is important constructive interference between the capture amplitudes from the two atoms in the molecule; (ii) the transition to ungerade states

of H_2^+ is unimportant, which tends to make the molecular cross section less than that for two isolated atoms; (iii) the capture amplitude from each atom is sensitive to the effective nuclear charge $Z \cong 1.17$ in H_2 rather than unity as in H. Consequently at high energies σ equals about 1.2–$1.4\sigma_{BK}$. The proton-proton interaction can be examined in the same way; the comparison of our results with those of Jackson and Schiff will be discussed.

* Supported in part by the Office of Naval Research.

D12. Optical Model Analysis of High-Energy Neutron Scattering.* E. D. REILLY, JR., *Knolls Atomic Power Laboratory*† AND J. MAYO GREENBERG, *Rensselaer Polytechnic Institute.*—The soft sphere approximation[1] has been used to calculate the scattering of neutrons from a potential, $V=-V_0(1+i\rho)$, $r \leq R$, and $V=-V_0(1+i\rho)\exp[-(r-R)/a]$, $r>R$, for energies greater than 40 Mev and for mass numbers greater than 50. The approximation can be shown to be reasonably accurate in this range. The parameters V_0, ρ, a, and R have been chosen to fit the calculated total and total minus elastic cross sections with experimental results. The values of the parameters so obtained join smoothly with values found from a partial wave analysis at lower energies and exhibit physically reasonable dependence on energy and mass number. The above potential form was chosen for reasons of analytical simplicity. Its parameters can be related simply to those of an equivalent Saxon well. Effects of nonsphericity are shown to be small.

* Work supported in part by a grant from the National Science Foundation.
† Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] E. W. Montroll and J. M. Greenberg, Phys. Rev. **86**, 889 (1952).

D13. Solution of Schrödinger Equation for a Particle Bound to More than One Spherical Potential. L. EYGES,* *Massachusetts Institute of Technology.*—We consider the quantum-mechanical problem of a particle bound to a configuration of spherical potentials, each of finite range. If the Schrödinger equation can be solved for each potential by itself, then it is shown how to solve it for the configuration, provided the potentials do not overlap. The energy levels are the zeros of a determinant of formally infinite order, but in practice this is always well approximated by a finite determinant, and often by one of small order. As illustrative examples we consider some states of a particle bound to three square wells with the configuration of an equilateral triangle, and to two truncated Coulomb potentials. The possibility of extending an approximate version of the method to overlapping potentials is pointed out.

* This work was done while the author held a National Science Foundation Senior Postdoctoral Fellowship.

THURSDAY MORNING AT 9:45

NBS, East Building

(M. GOLDHABER presiding)

Symposium of the Photonuclear Conference

DA1. Dispersion Theory of the Direct Photoeffect. G. E. BROWN, *Institute for Theoretical Physics, Copenhagen.* (30 min.)

DA2. Semiclassical Description of Photonuclear Giant Resonance. J. H. D. JENSEN, *Universitaet Heidelberg, Germany.* (30 min.)

DA3. The Photodisintegration of the Deuteron in the Medium-Energy Range. R. E. MARSHAK, *University of Rochester.* (20 min.)

DA4. Photon Interactions with Neutron-Proton Pairs in Complex Nuclei. J. H. SMITH, *University of Illinois.* (30 min.)

THURSDAY AFTERNOON AT 1:45

NBS, East Building

(L. KATZ presiding)

Photonuclear Phenomena

E1. Final-State Interactions in Photodisintegration of the Deuteron. A. F. NICHOLSON AND G. E. BROWN.—Early calculations which assumed Serber forces or simply neglected interactions in P states gave too low a total cross section and too little isotropic term in the angular distribution. One can show by a simple argument that interactions in the final states become relatively more important with increasing energy. Numerical calculations at 120-Mev c.m.s. using the Gammel-Thaler forces[1] give a total cross section and angular distribution in rough agreement with experiment,[2] without modifying the radiative interaction as proposed by Wilson[3] and Austern.[4]

[1] L. J. Gammel and R. M. Thaler, Phys. Rev. **107**, 1337 (1957).
[2] Ea. A. Whalin, Phys. Rev. **95**, 1362 (1954).
[3] R. R. Wilson, Phys. Rev. **104**, 218 (1956).
[4] N. Austern, Phys. Rev. **108**, 973 (1957).

E2. Mechanism for the Photodisintegration of Helium, Lithium, and Carbon from 50 to 160 Mev. J. H. SMITH AND S. I. BAKER, *University of Illinois, and the National Bureau of Standards.*—An investigation has been made to determine

whether the quasideuteron theory of the photodisintegration of complex nuclei remains valid at lower energies than those previously investigated. Protons with energies of from 28 to 100 Mev ejected from helium, lithium, and carbon by 164-Mev bremsstrahlung were observed alone and in coincidence with neutrons. Coincidences were observed at all proton energies down to 28 Mev. The spread in correlation angle between the neutron and proton was approximately that expected from nuclear momentum distributions. Crude activation curves were also taken which show that large fractions of the lowest energy protons were ejected by the $\gamma+A\rightarrow(A-1)+p$ process, whereas most of the higher energy protons were ejected from quasideuterons within the complex nucleus.

E3. Z Dependence of the Cross Section for High-Energy Photoprotons at 135°.* T. R. Palfrey, Jr., and G. W. Tautfest, *Purdue University*.—High energy protons ejected from various nuclei by 322-Mev bremsstrahlung from the Purdue electron synchrotron have been measured at 135°. Cross sections have been obtained as a function of Z for two proton energies: 93±5 Mev and 110±12 Mev. The latter energy interval is beyond the kinematically allowed limit for protons from the photodisintegration of real deuterons by 322 Mev γ rays. Protons detected in this region must be understood as coming from disintegration of high-momentum quasi-deuterons in the target nucleus, or from internal scattering of high-energy photoprotons (originally emitted at somewhat more forward angles) in the target nucleus. Preliminary analysis of the data gives the following cross sections in units of cm^2 sterad^{-1} Mev^{-1} Q^{-1} per target proton$\times10^{-32}$, with statistical accuracies of about 10%.

E_p	Li	Be	C	Al	Cu	Cd	Pd
93 Mev	3.2	4.3	4.7	5.2	5.3	6.5	7.2
110 Mev	1.3	1.8	2.3	2.4	2.9	3.3	2.9

The cross section does not have the strict linear dependence on Z found in most other angle and energy ranges.

* Supported in part by the U. S. Atomic Energy Commission.

E4. Photodisintegration of He^3.* L. Cranberg, *Los Alamos Scientific Laboratory*.—The photodisintegration of He^3 has been studied using a 22-Mev betatron as an x-ray source and nuclear emulsions as detectors. The energy distribution of the disintegration products may be partially resolved into two broad groups: a lower energy group corresponding to protons from the 3-body breakup and a higher energy group corresponding to protons from the two-body breakup. The data for energetic two-body breakup can be interpreted with least ambiguity and the excitation function for this process has been inferred for photon energy in excess of 13 Mev. The angular distribution of the two-body breakup products is given by $0.37+\sin^2\theta(1+0.8\cos\theta)$. The result for the three-body process is similar. Comparison is made with the theory.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. Verde, Helv. Phys. Acta 23, 453 (1950); J. C. Gunn and J. Irving, Phil. Mag. 42, 1353 (1951).

E5. Photodisintegration of Li^6.* D. G. Proctor† and W. H. Voelker, *Case Institute of Technology*.—The photodisintegration of Li^6 was investigated using a fast-slow coincidence system gating a 10-channel pulse height analyzer to detect neutron-proton coincidences and measure photoproton energies. Neutron-proton coincidence data indicate that there is no angular correlation between the neutron and proton, eliminating the possibility of a deuteron-alpha particle model for the Li^6 nucleus. Measurement of the photoproton energy spectrum and yield shows that, for 17.5-Mev bremsstrahlung, protons have energies as high as 9.2 Mev, leading to the conclusion that the Li$^6(\gamma,p)$He$^5\rightarrow$He^4+n reaction accounts for 30% of the neutron yield measured by Romanowski.[1] Yield measurements of photoneutrons above 1.3 Mev in coincidence with low energy protons show that 60% of the neutron yield could be attributed to the Li$^6(\gamma,n)$Li$^5\rightarrow$He^4+p reaction.

* Work supported by the U. S. Atomic Energy Commission.
† Now with Phillips Petroleum Company.
[1] Reported at Photonuclear Conference, November, 1956.

E6. Photoprotons from Nitrogen-15.* J. L. Rhodes, *Lebanon Valley College*, and W. E. Stephens, *University of Pennsylvania*.—Nitrogen gas enriched in N^{15} was exposed to bremsstrahlung of 18.7- and 24.6-Mev maximum energy from the University of Pennsylvania betatron. The ejected photoprotons were detected in nuclear emulsions, and the energy and angular distributions of the protons were measured. The photoproton yield at 24.6 Mev is 1.06(±0.14)×10^3 protons/at wt/r. Structure is observed in the cross section *vs* photon energy curve. The integrated cross section in the giant resonance region is 10 Mev-mb for ground-state transitions, while the integrated cross section up to 24.6 Mev for all photoprotons is 38±5 Mev-mb. The angular distributions of the various proton group fit curves of the form $A+B\sin^2\theta(1+\beta\cos\theta)^2$. For ground-state transitions the value of A/B is 1.39±0.44 for 1.8–8.0-Mev protons and 0.81±0.59 for 8.0–9.3-Mev protons, while for proton groups between 9.3 and 14 Mev the distributions are predominantly $\sin^2\theta$ with A/B lying between 0 and 0.26, and with the asymmetry coefficient β equal to 0.24.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

E7. Protons from the Photo- and Electrodisintegration of C^{12} and Al^{27}.* W. C. Barber, W. R. Dodge, and V. J. Vanhuyse,† *Stanford University*.—The magnetic spectrometer previously described[1] has been used to study the protons ejected from targets bombarded by the beam of the Stanford 40-Mev linear electron accelerator. Either the electron beam alone or a combination of the electron beam plus the bremsstrahlung from a thin radiator can be incident on the target. The protons from C^{12} have a narrow peak in the energy distribution at 6 Mev corresponding with photon absorption at the giant resonance followed by transitions to the ground state of B^{11}. A high-energy tail of protons extends to the endpoint of the photon spectrum and shows evidence for subsidiary peaks near 8.5 and 13.5 Mev. The angular distribution of those protons in the neighborhood of 6 Mev fits the form $1+1.3\sin^2\theta(1+0.3\cos\theta)^2$ for either the electron- or photon-induced processes. The protons from aluminum have a broad energy distribution with a peak near 4 Mev. As with carbon, the high-energy tail shows evidence of structure. The angular distribution changes gradually from nearly isotropic at 4 Mev to significantly forward at 13 Mev.

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.
† University of Ghent, Belgium.
[1] W. R. Dodge and W. C. Barber, Bull. Am. Phys. Soc. Ser. II, 2, 377 (1957).

E8. Total Gamma Absorption Cross Section of C^{12}.* M. Wolff, E. J. Winhold, W. E. Stephens, and E. E. Carroll, *University of Pennsylvania*.—We have measured total absorption cross sections in C^{12} from 20.3 to 20.8 Mev using monochromatic gamma rays from the T$^2(p,\gamma)$He^4 reaction. The resolution (70–100 kev) and sensitivity (8–10 mb) of the experiment were sufficient to detect reported structure in the nuclear giant resonance region. Changes in slope of Betatron yield curves for C$^{12}(\gamma,n)$ have been interpreted[1] as resonances in the nuclear cross section. For resonances of width 70 kev, we could have detected an integrated cross section >0.7 Mev-mb. This is ½ to ⅓ of the values reported in this region. No such resonances were found. Our results are not inconsistent with the broader structure reported from

$C^{12}(\gamma,p)$.[1]—Preliminary calculations of the absolute total cross section are in agreement with the tabulated values.[2]

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by the National Science Foundation.

[1] Katz, Haslam, Horsley, Cameron, and Montalbetti, Phys. Rev. 95, 464 (1954).
[2] Cohen, Mann, Patlon, Reibel, Stephens, and Winhold, Phys. Rev. 104, 108 (1956).
[3] National Bureau of Standards, Circular 583.

E9. Mass-Absorption Coefficients for 40- to 80-Mev X-Rays in Carbon, Water, and Aluminum. J. M. WYCKOFF AND H. W. KOCH, *National Bureau of Standards.**—A good geometry measurement has been made of 90-Mev synchrotron x-ray spectra transmitted through long cylinders of carbon, water, and aluminum. A "hydrogen" measurement was made using a cyclohexane-benzene difference method. The x-ray detector system was a 5-in. diam by 9-in. long NaI(Tl) spectrometer and a 256 channel pulse-height analyzer. The pulse-height distributions clearly show the nuclear absorption below 40 Mev. The distributions also permit an accurate evaluation of the total absorption processes in the energy range from 40 to 80 Mev. The carbon measurement at 60 Mev gives $\tau=0.01434\pm0.00005$ cm²/g which is 1%[1] and 5%[2] higher respectively than the published values. The values measured for water and aluminum at 60 Mev of 0.0170 and 0.0239 cm²/g are also higher. For hydrogen at 60 Mev $\tau=0.0128$, a value between those in the two tables. The differences are largely accounted for by the triplet cross section estimates of Joseph and Rohrlich.[3]

* Supported in part by the Office of Scientific Research of the Air Research and Development Command, U. S. Air Force.
[1] G. White, NBS Report 1003 (unpublished); K. Siegbahn, *Beta- and Gamma-Ray Spectroscopy* (Interscience Publishers, Inc., New York, 1955).
[2] G. White Grodstein, NBS Circular 583 (1957).
[3] J. Joseph and F. Rohrlich, Revs. Modern Phys. (to be published).

E10. Measurements of (γ,d) and (γ,np) Reactions in the Threshold Region.* J. GOLDEMBERG AND L. MARQUES, *University of Sao Paulo and Centro Brasileiro de Pesquisas Fisicas.*—A report is made on measurements of (γ,d) and (γ,np) reactions in S^{32}, Zn^{64}, Zn^{66}, and Fe^{54}; radiochemical methods were used to separate the parent from the daughter nucleus respectively P^{30}, Cu^{62}, Cu^{64}, and Mn^{54}. Great care was taken in measurements in the 2-Mev region above the (γ,d) and below the (γ,np) threshold. The results show that in this region the (γ,d) cross section goes through a resonance with a maximum of about 1 mb, in the cases of Zn^{64} and Zn^{66}; at energies above the (γ,np) threshold the cross section rises again to ~3 mb and goes probably through a second maximum. In Fe^{54} (γ,d) and (γ,np) reactions were not found and an upper limit for them was found.

* This work was supported in part by the Conselho Nacional de Pesquisas.

E11. Angular Distribution of Photofission Fragments.* L. KATZ AND S. KOWALSKI, *University of Saskatchewan*, AND F. BROWN AND A. BAERG, *Chalk River Laboratories.*—The angular distribution of photofission fragments using balanced ionization chambers have been measured for a number of fissile materials. Measurements on thorium with 10-Mev bremsstrahlung at 0°, 25°, 45°, 60°, and 90° showed the angular distribution to be of the form $1+\alpha\sin^2\theta$, with $\alpha=1.55\pm0.10$. The values of α determined from 0° and 90° measurements as a function of bremsstrahlung energy are shown in Table I.

TABLE I.

Energy (Mev)	$\alpha_{Th^{232}}$	$\alpha_{U^{233}}$	$\alpha_{Pa^{239}}$	$\alpha_{U^{238}}$
6.0		6.6±2.3		
6.5	38±15	4.4±1.0		
7.0	13±2.8	2.2±0.3		
7.5	10.2±1.3			
8.0	4.6±0.7	1.27±0.14	0.00±0.06	0.05±0.07
9.0	2.8±0.4	0.41±0.05		
10.0	1.8±0.1		0.01±0.04	0.03±0.04
14.0	0.46±0.09	0.09±0.04		
20.0	0.14±0.06	0.05±0.03	−0.05±0.03	−0.01±0.03

* This work is supported by the Canadian National Research Council and the Atomic Energy of Canada Limited.

E12. Scattering of 6-Mev Gamma Rays. SVEN A. E. JOHANSSON, *University of Lund* (introduced by H. W. Koch).—The scattering of 6-Mev gamma rays in several heavy elements has been investigated. The gamma-ray source was the reaction $F^{19}(p,\alpha)O^{16}$. The spectrum of the scattered radiation was recorded by means of a big sodium iodide crystal and a multichannel pulse-height analyzer. The spectra are rather similar for all the elements investigated (W, Hg, Bi, Pb, Th, U). They are composed of a continuous distribution because of the inelastic scattering and a well-defined peak due to the elastic scattering. The shape of the inelastic part gives information about the level density in the scattering nucleus. The interpretation of the elastic peak will be discussed. The experiment also gives the cross section for photon absorption at 6 Mev since gamma-ray scattering is the only possible reaction at this energy (except for fission in Th and U). The inelastic cross section is of the order of 50 mb and the elastic cross section 1–2 mb.

E13. Nuclear Resonance Scattering of 7-Mev Photons by Lead.* K. REIBEL AND A. K. MANN, *University of Pennsylvania and Brookhaven National Laboratory.*—The cross sections for nuclear resonance scattering of 6.91- and 7.14-Mev gamma rays by lead have been measured. The incident radiation is produced in the reaction $F^{19}(p,\alpha\gamma)O^{16}$; at proton energies of 2.05 and 2.40 Mev, each of the lines has a Doppler broadened total width of about 130 kev and the ratios of the intensities of the 7.14- and 6.91-Mev radiations are approximately 4.0 and 0.25, respectively.[1] Preliminary measurements indicate that: (a) $\langle\sigma\rangle_{7.1}/\langle\sigma\rangle_{6.9}\simeq3.5$, (b) $\sigma(\theta)_{7.1}\sim1+\cos^2\theta$, and (c) $\langle\sigma\rangle_{7.1}=18\pm4$ mb. Assuming electric dipole transitions, as suggested by the angular distribution, the ratio of level width to level spacing, Γ/D, is found to be of order 10^{-4}, in agreement with the value obtained using bremsstrahlung.[2] Measurements of the angular distribution at 6.91 Mev and of peak absorption cross sections are in progress and will also be discussed.

* Research supported in part by the U. S. Air Force, OSRD.
[1] C. P. Swann and F. R. Metzger, Phys. Rev. 108, 982 (1957).
[2] E. C. Fuller and E. Hayward, Phys. Rev. 101, 692 (1956).

E14. Theory of High-Energy Bremsstrahlung and Pair Production in a Screened Field. HAAKON OLSEN AND HARALD WERGELAND, *Fysisk Institutt, N. T. H., Trondheim, Norway*, AND L. C. MAXIMON,* *Department of Theoretical Physics, The University, Manchester, England.*—The differential cross sections for high-energy bremsstrahlung and pair production in a screened Coulomb field are calculated without the use of the Born approximation. The cross sections are evaluated by using wave functions which are accurate in the region in space which contributes significantly to the matrix element. This region is determined by the order of magnitude of q, the momentum transfer, and different wave functions must be used in the regions (I) corresponding to q's of order mc and (II) corresponding to q's of order (mc^2/E) mc, where E is the energy of the electron. The integrated cross section for pair production, including screening, has already been given by Davies, Bethe, and Maximon, and it was shown by Olsen that the cross section for bremsstrahlung integrated over the direction of motion of the final electron can be inferred from the corresponding expression for pair production. This has been extended to include the arbitrary specification of spins and polarization of particles and photon. As in the case of pair production summed over spins and polarization, the correction to the cross section is additive: one part is the Bethe-Heitler cross section including screening; to this is then added the Coulomb correction which is independent of screening.

* Work partly supported by a grant from the National Science Foundation.

THURSDAY AFTERNOON AT 2:00

Sheraton Hall

(R. L. GARWIN presiding)

Strange Particles II

EA1. Calculation of the Masses of the Elementary Particles. LEONARD S. LEVITT, *Stevens Institute of Technology.*—The formula, $M=n_1M_0+(n_2+\frac{1}{2}n_3-9/2n_1)/\alpha$, which permits the calculation of the masses of essentially all the known (as well as some unknown) elementary particles, is derived. In this equation M is the mass (in units of electron masses) of the desired particle, $M_0=2454$, α is the fine structure constant ($=1/137$), and the n's are zero or small integers, and may therefore be called "mass quantum numbers." Table I gives the values the n's must have in order to reproduce the elementary particle masses, and compares the calculated and observed mass values. The significance of the mass quantum numbers will be discussed.

TABLE I.

Particle	n_1	n_2	n_3	Calc. mass	Obs. mass
$\mu^\pm$	0	1	0	206	207
$\pi^\pm(\pi^0)$	0	0	2	274	273(264)
$\tau^\pm(\theta^0)$	0	2	4	959	966(965)
$p^+(n^0)$	1	0	0	1837	1836(1839)
Λ^0	1	1	1	2180	2181
$\Sigma^\pm$	1	1	2	2317	2327
Ξ^-	1	1	4	2591	2586

EA2. Strange Particle Results from a Multiplate Cloud Chamber.* D. O. CALDWELL, E. BOLDT, H. BRIDGE, AND YASH PAL, *M.I.T.*—The large M.I.T. multiplate cloud chamber has been exposed to 1.8-Bev π^- and 2.6-Bev proton beams at the Brookhaven Cosmotron. The pictures have all been scanned, and the events have been measured and analyzed using an IBM 650 computer. Final results on the strange particle production cross sections, preliminary values for which have already been reported,[1] will be given, as will branching ratios for the neutral decays of the θ^0[1] and Λ^0. Mass values for the Λ^0 and θ^0 will be presented, along with information on lepton decays of the Λ^0. Preliminary values of the lifetimes of the Λ^0 and θ_1^0 are, respectively, $(2.5\pm0.2)\times10^{-10}$ sec and $(1.0\pm0.1)\times10^{-10}$ sec, and final values will be given. The decay of the Λ^0 is a single exponential out to at least three mean lives.

* This research is supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Boldt, Bridge, Caldwell, and Pal, "International Conference on Mesons and Recently Discovered Particles," Padua-Venice (1957).

EA3. Mesic Decays of Hypernuclei from K^- Captures. I. Binding Energies.* R. LEVI-SETTI, R. G. AMMAR, AND W. E. SLATER, *University of Chicago,* AND S. LIMENTANI, J. H. ROBERTS, P. E. SCHLEIN, AND P. H. STEINBERG, *Physics Department, Northwestern University.*—Two 4×6-in. emulsion stacks were exposed to the 300 Mev/c enriched K^- beam at the Bevatron.[1] These stacks were composed as follows: (a) 59 1.2-mm K-5 pellicles plus 41 0.6-mm 2X diluted K-5 pellicles; (b) 59 K-5 and 71 L-4 0.6-mm pellicles. About 5×10^4 K^- stop in these stacks. Scanning preferentially for mesic hyperfragments, we have found to date 30, at N.U. and 100 at E.F.I.N.S. such events, form about 1.5×10^4 K^- captures. Measurements of the events are in progress, and accurate binding energy value will be presented in continuation of previous work on this subject.[2] Byproducts are momentum-range curves for low velocity heavy ions.

* Research supported by the U. S. Air Force Office of Scientific Research (at E.F.I.N.S.) (U. of Chicago) and by the National Science Foundation and by the U. S. Atomic Energy Commission through Argonne National Laboratory subcontract (Northwestern).
[1] Exposure made possible through the kind cooperation of Dr. E. J. Lofgren and the Bevatron staff.
[2] Levi-Setti, Slater, and Telegdi, *Proceedings of the Seventh Annual Rochester Conference* (Interscience Publishers, Inc., New York, 1957).

EA4. Mesic Decays of Hypernuclei from K^- Captures. II. Decay Modes.* P. H. STEINBERG, S. LIMENTANI, J. H. ROBERTS, AND P. E. SCHLEIN, *Northwestern University,* AND R. G. AMMAR, R. LEVI-SETTI, AND W. E. SLATER, *University of Chicago.*—Dalitz has pointed out[1] that, from the branching ratios of the various mesic decay modes of hypernuclei valuable information, in particular, concerning spins, can be extracted. Such branching ratios are being obtained from the events referred to in the preceding abstract.[2] At present the following preliminary information is available: number of two body collinear decays (of H^3, H^4, and certain heavier hypernuclides) 30; decays into two noncollinear charged particles, probably involving the additional presence of at least one neutron, 18; three-body decays, 75; more complex disintegrations, 7. Detailed results will be presented for individual hypernuclides.

* Research supported by National Science Foundation, and by the U. S. Atomic Energy Commission through Argonne National Laboratory subcontract (Northwestern); and by the U. S. Air Force Office of Scientific Research [(at E.F.I.N.S.) U. of Chicago].
[1] R. H. Dalitz, Repts. Progr. in Phys. 20, 163 (1957).
[2] Levi-Setti, Ammar, Slater, Limentani, Roberts, Schlein, and Steinberg, (preceding abstract).

EA5. Study of Mesonic Hyperfragments in G5 Emulsion Exposed to 4.7 Bev/c π^- Beam.* PETER E. SCHLEIN, S. LIMENTANI, J. H. ROBERTS, AND PHILLIP H. STEINBERG, *Northwestern University.*—A 10-in.[2] emulsion stack was exposed to the Berkeley 4.7 Bev/c π^- beam. In area scanning the 66 500 interaction stars, we found 36 hyperfragments (11 mesonic, 25 nonmesonic) and 61 secondary events with connecting tracks $<\sim15$ μm. Studies have been made of only those events which decay mesonically. Of the 11 mesonic decays found, five furnish binding energies, two of the pions leave the stack, two interact in flight, one event has a nonmeasurable recoil, and one is an anomalous event. We report the following binding energies ($Q=37.22$ Mev assumed): Event 119 $-Li^8$, 6.42 ± 0.67 Mev; 194 $-Li^7$, 5.25 ± 0.40; 167 142 $-He^6$, 213 ±0.53 and 2.01 ± 0.45; 156 $-Li^8$, Be^8, 5.07 ± 0.5. Unambiguous identifications of events 119, 194, 167, 142 are made completely on the basis of kinematical analysis. In addition, preliminary profile measurements of event 119 seem to be consistant with its identification as Li^8. In view of the uniqueness of this event, remeasurement is in progress. Profile study of the 72 μm connecting track of event 156 should provide discrimination between Li^8 and Be^8. Errors stated are random and do not include errors in Q (0.2 Mev) and $R-E$ relation (Barkas).

* Supported by the National Science Foundation and the U. S. Atomic Energy Commission through Argonne National Laboratory Subcontract.

Invited Papers

EA6. Electron-Pion Production and Nuclear Structure. W. K. H. PANOFSKY, *Stanford University.* (30 min.)

EA7. Electromagnetic Separators for High-Energy Particle Beams. J. J. MURRAY, *University of California, Berkeley.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Sheraton-Park, Burgundy Room

(JOHN HARVEY presiding)

Neutron Physics II

F1. Potential Scattering of Ag^{109} and Ag^{107} for Low-Energy Neutrons.* R. L. ZIMMERMAN AND D. J. HUGHES, *Brookhaven National Laboratory.*—The low-energy potential scattering cross section, which is directly related to the nuclear radius, has been measured[1] for many normal elements. In order to investigate a possible difference for the individual silver isotopes, the total cross sections of separated samples of Ag^{109} and Ag^{107} have been measured in the energy region from 10 to 120 ev. For each isotope the contributions of all known positive energy levels to the observed cross section between resonances was subtracted. The resulting residual cross section would be the potential cross section were it not for the effect of negative energy levels, which may be particularly important at low energy. Since the potential scattering is constant, the energy variation of the residual cross section can be used to measure the nearby negative energy levels. In this way it was found that a strong level in Ag^{107} at about $E_0=-10\pm5$ ev is needed to explain the scattering cross section at low energies and the large thermal absorption cross section. No significant negative level was observed in Ag^{109}. The potential scattering cross sections obtained in this way are 5.5 ± 1.0 b and 6.5 ± 0.5 for Ag^{109} and Ag^{107}, indicating no significant difference in cross section, hence in nuclear radius.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] Seth, Hughes, Garth, and Zimmerman, Phys. Rev. (to be published).

F2. *g*-Value Assignment by Neutron Scattering Measurements.* F. B. SIMPSON AND R. G. FLUHARTY, *Phillips Petroleum Company.*—The statistical factor g, for resonances observed by low-energy neutrons, is frequently known to be one of two possible values since the target nucleus spin is known and only S wave interactions are observed. If one assumes that the capture width is the same for all levels, the area from a thin sample scattering measurement and the area from a thin sample total cross section measurement are sufficient to make the spin assignment. If Γ_γ is known, g can be measured directly. The approach appears useful for cases where Γ_n is of the same order of magnitude or less than Γ_γ. Analyses of tungsten scattering resonances combined with known total cross section data will be presented. Preliminary analyses assign g values of $\frac{3}{4}$, $\frac{1}{4}$, and $\frac{1}{4}$ to the 27-, 46-, and 102-ev resonances, respectively. A description of the experimental arrangement used, and the operational time required to apply the technique, will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

F3. Neutron Strength Functions ($\overline{\Gamma}_n^0/D$).* O. D. SIMPSON, R. G. FLUHARTY, AND R. S. SHANKLAND,† *Phillips Petroleum Company.*—A thin sample technique for measuring the average $\overline{\Gamma}_n^0/D$ from 20 ev to 1 kev on the MTR fast chopper has been developed. The data are taken at 16 m to provide high counting rates for good statistical accuracy, since small differences between sample and open-beam data are involved. To minimize fluctuations, the samples are cycled in and out of the beam at 10-min intervals, and the data are successively stored in different portions of the 1024-channel memory. The analysis is made on the IBM 650 computor. Experimental variations between individual runs agree well with those expected from error analysis. It is expected that data on other elements will be available, since the procedure is now routine for most total cross section studies.

Sample	Isotope	No. of runs	Average $(\overline{\Gamma}_n^0/D)\times10^4$
U	235	14	0.90 ± 0.1
Au	197	4	1.14 ± 0.1
Ta	180	2	2.00 ± 0.24
Sm	149	1	3.11 ± 0.28
Cd	Natural	1	0.42 ± 0.16
Mo	Natural	1	0.28 ± 0.11

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Case Institute of Technology.

F4. Thermal Diffusion Isotope Enrichment of Xenon and Its Total Neutron Cross Section.* D. P. MANN AND W. W. WATSON, *Yale University,* AND R. B. SCHWARTZ, *Brookhaven National Laboratory.*—Using a multistage hot-wire thermal diffusion apparatus of 12 m total length and the gas-displacement method of Clusius and Bühler,[1] we have been producing light and heavy samples of xenon enriched to 52% Xe^{129} and 27% Xe^{136}, respectively, at a rate of about 70 cm^3 every 10 days (the equilibrium period). Defining the separation factor as the ratio of the concentration of Xe^{124} to that of Xe^{136} at the top of the apparatus divided by the corresponding ratio at the bottom, we obtain a value of about 7. Suitable gas holders of Armico iron have been constructed for use with the BNL fast chopper. Enriched sample thicknesses are about 3.3 g/cm^3, requiring 160 cm^3 (NTP) of gas at 1500 lb/in.^{2}. Preliminary low resolution measurements indicate a splitting of the 13.9-ev resonance.[2] Several smaller resonances at higher energies are also evident. Further measurements are being undertaken.

* Supported in part by the U. S. Atomic Energy Commission.
[1] K. Clusius and H. Bühler, Z. Naturforsch. **9a**, 775 (1954).
[2] S. P. Harris, Phys. Rev. **89**, 904 (1953).

F5. Total Cross Sections of Pu^{241}.* ROBERT B. SCHWARTZ, *Brookhaven National Laboratory.*—The total neutron cross sections of Pu^{241} have been measured from 0.01 to 50 ev with the BNL fast chopper. The measurements were taken with a 175-mg sample of plutonium containing 62% Pu^{241}, 24% Pu^{240}, 12% Pu^{239}, and 2% Pu^{242}. For the prominent resonance at 0.25 ev, preliminary analysis yields the parameters $\Gamma=0.125$ ev and $\sigma_0\Gamma=240$ b-ev. Combining these resonance parameters with fission data taken at Hanford Laboratories,[1] one obtains $\Gamma_\gamma=0.030$ ev and $\Gamma_f=0.095$ ev for this level. More detailed analysis of the low-energy cross sections is under way, as well as analysis of the higher energy resonances. The situation is greatly complicated by the fact that in addition to all the levels in all the plutonium isotopes, the cross section spectrum is confused by the presence of levels in Am^{241}, formed in the beta decay of Pu^{241}.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] B. R. Leonard (private communication).

F6. Capture Gamma Rays in Individual Neutron Resonances.* J. D. FOX, M. K. BRUSSEL, R. E. CHRIEN, R. L. ZIMMERMAN, AND D. J. HUGHES, *Brookhaven National Laboratory.*—Preliminary experiments are now in progress with the Brookhaven fast chopper to investigate the possibility of studying capture gamma rays in individual neutron resonances. Gamma rays following neutron capture are detected by a 3-in. diam×3-in. thick NaI(Tl) crystal and the pulses

are analyzed with a single channel pulse-height analyzer and a 1024-channel time-of-flight analyzer. In practically all elements, resonances have been assigned to isotopes by means of total cross-section measurements with separated isotopes so that capture gamma rays from an individual resonance can now be associated with a definite isotope. In favorable cases, it will be possible to assign spins to the resonances because of the presence or absence of ground-state transitions.[1] In spite of low counting rates with the present equipment, it has been shown in the case of W that high-energy gamma rays (~7 Mev) are present in some of the resonances in W^{183} but not in levels of the other isotopes of lower binding energy. Higher resolution measurements are now being performed to determine the spins of the W^{183} levels by identification of the ground-transition (7.4 Mev).

* Under the auspices of the U. S. Atomic Energy Commission.
[1] H. H. Landon and E. R. Rae, Phys. Rev. 107, 1333 (1957).

F7. Gamma-Ray Spectra from Neutron Capture in Resonances of Mn^{55}, Hg^{198}, and Hg^{199}.* T. J. KENNETT, L. M. BOLLINGER, AND R. T. CARPENTER, *Argonne National Laboratory.*—Gamma-ray spectra resulting from the capture of neutrons in the resonances of Mn^{55}, Hg^{198}, and Hg^{199} were measured with NaI scintillators, using the Argonne fast chopper to select the incident neutron energy. The Mn resonances at 337 and 1080 ev, having $J=2$ and $J=3$, were studied. The spectrum for the 337-ev resonance is similar to that for thermal neutrons, as expected from cross-section results. The combined results for the two resonances having different spins gives information about the properties of low-energy states in Mn^{56}. For thermal neutron capture by Mn^{55}, coincidence measurements showed the existence of the following gamma-ray cascades (energy in Mev); 7.15−0.09; 7.05−0.22, 6.78−0.28−0.22, and 6.43−0.33−0.28−0.22. For Hg^{199}, the 23-ev resonance was investigated. A strong line of 6.3 Mev, probably owing to a transition to the 0.209 Mev level, was observed. For Hg^{199} the 34-ev resonance was studied. A strong ground-state transition was observed, confirming the previous assignment[1] of $J=1$ to the resonance. Other resonances in mercury are being studied in the same way.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. H. Landon and E. R. Rae, Phys. Rev. 107, 1333 (1957).

F8. Low-Energy Gamma Rays from Thermal Neutron Capture.* J. E. DRAPER AND C. K. BOCKELMAN, *Yale University.*—The prominent gamma rays following thermal neutron capture have been investigated. The neutrons were obtained from the 6-Mev electron linear accelerator utilizing the $Be(\gamma,n)$ reaction. The samples were placed beside the neutron source and were viewed through Pb collimation by a 2.5-in. by 1.7-in. NaI(Tl) scintillator at a distance of 3 m from the sample. The energies in kev of the prominent gamma rays (in addition to the K x-rays) were: Rh−42, 94, 131, 185; Ag−69, 110, 196; Sb−75, 115, 150, 325; Te−608; I−135, Gd−85, 190; Dy−195, 405; Ho−146, 248; Tm−160, 222; Ta−132, 175, 280, 405; Pt−345. The gamma-ray energy uncertainty is the larger of ±7% or ±5 kev. Information will be presented concerning the relative intensities of the gamma rays.

* Supported by the U. S. Atomic Energy Commission.

F9. Neutron Resonance Parameters of Pm^{147} and Am^{241}. R. C. BLOCK, J. A. HARVEY, AND G. G. SLAUGHTER, *Oak Ridge National Laboratory.*—The total neutron cross sections of fission product Pm^{147} (2.5-yr half-life) and Am^{241} (470-yr half-life) were measured with the old ORNL fast chopper time-of-flight spectrometer. Transmission measurements were made on two samples of Pm^{147} (6.8 and 27 mg) from 0.2 to 50 ev. In the energy range from 0.2 to 20 ev, six resonances were observed in Pm^{147}. Parameters have been determined for these resonances. An average level spacing per spin state of 7±2 ev, and a Γ_n^0/D ratio of $(3.0\pm1.1)\times10^{-4}$ have been obtained for this nuclide. Am^{241} exhibits six resonances in the energy range from 0.2 to 3 ev. These measurements are being repeated with a new chopper, and the results will be presented.

F10. Slow Neutron Resonances in Europium Isotopes.* FAHRI DOMANIC† AND EUGENE T. PATRONIS, JR., *Brookhaven National Laboratory.*—The total cross sections of highly enriched samples of Eu^{151} and Eu^{153} have been measured from 1 ev to 10 ev using the BNL crystal spectrometer (resolution 0.17 μsec/m). The Eu^{153} resonances at 2.46, 3.29, 3.94, 6.20, and 8.90 ev have been analyzed and the Breit-Wigner parameters for these resonances will be given. The parameters obtained for the Eu^{153} resonances will be compared with those for Eu^{151}.

* Work supported by U. S. Atomic Energy Commission.
† On leave from University of Ankara, Ankara, Turkey.

F11. Spin States for Resonances in W^{183}, Ag^{107}, and Ag^{109}. J. A. HARVEY, G. G. SLAUGHTER, AND R. C. BLOCK, *Oak Ridge National Laboratory.*—Measurements have been made of the number of neutrons scattered as a function of energy from thin W and Ag targets in the energy range from 20 to 150 ev with the new high-intensity fast chopper time-of-flight spectrometer. Total cross-section measurements have also been made on these elements, and when these are compared to the scattering measurements, assignments of the spins of the compound states (0 or 1 for these nuclides) can be made. The spin states of the levels corresponding to the resonances at 27.1, 46.6, 48.1, and 102 ev in W^{183} have been determined using the scattering of the two resonances at 21.2 and 117 ev in W^{183} (for which $g=1$) for calibration. Since the resonances at 27 and 46.6 ev have neutron widths much greater than their radiation widths, it is possible to determine the spins of these states from thick- and thin-sample total cross-section measurements. These total cross-section results agree with those from the scattering measurements. Results from scattering measurements on silver for the 52, 57, and 72 ev resonances agree with previous assignments. Corrections are being made for multiple scattering in the sample, and results on other resonances will be presented.

F12. Parameters of Neutron Resonances in Ag, I, and Au. G. G. SLAUGHTER, R. C. BLOCK, AND J. A. HARVEY, *Oak Ridge National Laboratory.*—Total cross-section measurements have been made on thick and thin samples of Ag, I, and Au from 20 to 400 ev with the new ORNL high-intensity fast chopper time-of-flight spectrometer. With a 45-m flight path and a 2.6 μsec burst, a resolution of 0.06 μsec/m is realized. Transmission measurements have been analyzed by the area method to give the parameters of the resonances. For I and Au these parameters have been determined up to ~200 ev with considerably more accuracy than the values that have been reported. Parameters of several additional resonances at higher energies have been obtained. The strength functions (Γ_n^0/D) have been computed for these elements and will be compared to theoretical predictions of various nuclear models.

F13. Spins of Neutron Resonances. A. STOLOVY AND M. E. BISHOP, *Naval Research Laboratory.*—A program has been undertaken to measure the spins of neutron resonances by studying the interaction of polarized neutrons with polarized nuclear samples. The nuclear polarization is accomplished by the "brute force" technique;[1] the sample is brought to ~0.01°K by contact with an adiabatically demagnetized salt and placed in a magnetic field of 19 kilogauss. Neutrons from the NRL reactor are polarized by transmission through thick blocks of magnetized steel, and resonance filters are

used to select bands of neutron energies. The neutron orientation in flight is controlled by fields produced by current-carrying copper bars. Transmission measurements made with the spins of the neutrons and nuclei parallel and antiparallel are compared to obtain the spin of the level responsible for the resonance. The results of preliminary measurements will be presented.

[1] Dabbs, Roberts, and Bernstein, Phys. Rev. 98, 1512 (1955).

THURSDAY AFTERNOON AT 1:45

Sheraton-Park, Continental Room

(A. N. HOLDEN presiding)

Paramagnetic Resonance; Cyclotron Resonance

FA1. Zero-Field Splitting in Nickel Fluosilicate.* W. M. WALSH, JR.,† *Harvard University.*—Paramagnetic resonance measurements of the zero-field splitting D in single crystals of $NiSiF_6 \cdot 6H_2O$ have been made as a function of hydrostatic pressure P,[1] and uniaxial stress U, the latter being applied along the crystalline symmetry axis. The results are $1/D(\partial D/\partial P)_T = -1.60\times10^{-4}$ (kg/cm²)$^{-1}$ and $1/D(\partial D/\partial U)_T = 3.18\times10^{-4}$ (kg/cm²)$^{-1}$ respectively. The anisotropic changes in sample dimensions due to these forces as well as the thermal expansion have been measured. Combining these data with the temperature dependence of D[2] permits a phenomenological calculation of the zero-field splitting dependence on unit cell shape and volume and of the explicit temperature dependence due to lattice vibrations.

* Supported by a Joint Services Contract.
† General Electric Company Fellow.
[1] W. M. Walsh, Jr., and N. Bloembergen, Phys. Rev. 107, 904 (1957).
[2] R. P. Penrose and K. W. H. Stevens, Proc. Phys. Soc. (London) A63, 29 (1950).

FA2. Paramagnetic Resonance in Neutron-Irradiated LiF.* Y. W. KIM, R. KAPLAN, AND P. J. BRAY, *Brown University.*—In previous investigations[1-3] of the F-center electron-spin resonance in irradiated LiF, the observability of the expected 19 hyperfine components or a lesser number has depended on the type and amount of irradiation received. We have observed the full 19 lines in specimens which have received approximately 5×10^{17} nvt at room temperature. The splittings are quite distinct when H_0 is in a (1,0,0) or (1,1,0) direction but disappear at intermediate H_0 orientations in a (1,0,0) plane. They are most distinct when H_0 is in a (1,0,0) direction. The experimental envelope of the derivative curve disagrees grossly with that obtained from the predicted Gaussian absorption shape. Further, absorption on either side of the resonance is observed beyond the ninth component as far out as six or more additional splittings. Additional lines in those regions may have been observed. It is possible that V centers[1] or other centers may be influencing the line so markedly. Dipole-dipole interactions between F-center electrons and the presence of Li^6 nuclei are also considered.

* Research supported by the U. S. Atomic Energy Commission under Contract AT(30-1)2024.
[1] E. E. Schneider, Phys. Rev. 93, 919 (1954).
[2] N. W. Lord, Phys. Rev. 105, 756 (1957).
[3] G. J. Wolga and M. W. P. Strandberg, Bull. Am. Phys. Soc. Ser. II, 2, 36 (1957).

FA3. Paramagnetic Resonance of *F* Centers in Potassium Iodide. GORDON A. NOBLE, *Zenith Radio Corporation.*—The paramagnetic resonance absorption of additively colored potassium iodide has been observed at 300°K, 77°K, and 4.2°K. The microwave frequency was about 9 kMcps and the magnetic field was modulated at 25 cps. The g factor is 1.971 ±0.001 and is independent of temperature. The width between points of maximum slope is about 200 gauss and is independent of temperature at low power. The absorption signal as a function of magnetic field is approximately Gaussian. The saturation of the resonance has been measured at the three temperatures and indicates qualitatively the dependence of T_1 on temperature. The importance of the next nearest neighbor interaction is apparent when the Δg value, 0.031, for KI is compared to the values 0.022 for KBr and 0.006 for KCl. These results will be related to previous studies of F centers.

FA4. Paramagnetic Resonance and Optical Absorption in Silver-Doped Alkali Halides.* W. HAYES, C. J. DELBECQ, AND P. H. YUSTER, *Argonne National Laboratory.*—The paramagnetic resonance and optical absorption spectra of LiCl, NaCl, KCl, and RbCl doped with silver ions have been investigated. Before irradiation no optical absorption is found in the near ultraviolet and visible regions of the spectrum and no electron resonance is observed. After irradiation with x-rays for about 15 minutes at 77°K electron resonances appear in each crystal which are assigned to Cl_2^{-1} and neutral silver atoms. Optical absorption bands associated with these resonances occur at 350–450 mμ and 400–500 mμ, respectively. In the case of NaCl and KCl the Cl_2^- resonance disappears on warming past the first glow which occurs at about 200°K for KCl and 150°K for NaCl; a new resonance is then observed which is assigned to a hole center localized on a silver ion and two chlorine ions. There are three centers in the magnetic unit cell each with similar spectra and with axial symmetry about each of the cube edges. Optical absorption bands associated with these centers have been observed. On irradiating into the optical absorption band of these high temperature hole centers in KCl at 4°K with light polarized in the [100] direction a dichroism is subsequently observed in the optical absorption spectrum which is consistent with the axial symmetry of the resonance spectrum.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. Kanzig, Phys. Rev. 99, 1890 (1955).

FA5. Paramagnetic Resonance and Optical Absorption in KCl Crystals Doped with Barium, Strontium, and Calcium Ions.* G. M. NICHOLS AND W. HAYES, *Argonne National Laboratory.*—The paramagnetic resonance and optical absorption spectra of KCl single crystal doped with divalent barium, strontium, and calcium ions have been investigated. After about one hour of x-irradiation at 195°K, a resonance spectrum is observed with three centers in the magnetic unit cell; the centers are similar and each has axial symmetry about a different cube edge. The optical absorption spectrum shows a band near 324 mμ which arises from the same centers. Upon irradiation into the optical absorption band with light polarized along the (001) axis a dichroism is observed in the absorption spectrum and the resonance spectrum shows that

the number of (001) oriented centers is reduced while the number of (100) and (010) oriented centers is unchanged. The centers are assigned to a Cl_3^- molecule ion and are closely related to the Cl_2^- ions described by Känzig.[1] The chlorine nuclei occupy unequivalent sites and hence the chlorine hfs in the resonance spectrum is extremely complicated. The model which is proposed for these centers involves a large initial concentration of positive ion vacancies; this is expected to result from the presence of the divalent impurities.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. Känzig, Phys. Rev. 99, 1890 (1955).

FA6. Electron Spin Resonance of Free Radicals in Ultraviolet Irradiated Hydrocarbons, Aldehydes, and Ketones.* CHARLES P. POOLE, JR., AND ROY S. ANDERSON, *University of Maryland.*—Unsaturated hydrocarbons, aldehydes, and ketones, maintained at 77°K, have been exposed for approximately 6 hr to the ultraviolet radiation from a high-pressure mercury arc. Electron spin resonance spectra, observed at a g factor of 2 with a 9000-Mc spectrometer, are characteristic of the substances irradiated. Interpretation of specific hydrocarbon cases will be used to show that the characteristic hyperfine structure may be attributed both to hyperconjugation and the $\sigma-\pi$ interaction between the unpaired electron and neighboring hydrogen atoms in the radical. Aldehydes and ketones produce singlets attributed to formyl (CHO) and alkanoyl (RCO) radicals. The strong electronegativity of the oxygen on the carbonyl group (CO) suppresses the contact hyperfine interaction between the free electron and neighboring hydrogen atoms. Alkyl radicals formed simultaneously with the alkanoyl radicals appear similar to the photolysis products of unsaturated hydrocarbons.

* This research has been supported by a contract monitored by the U. S. Air Force Office of Scientific Research of the Air Research and Development Command.

FA7. Electron Spin Resonance of Free Radicals at Liquid Helium Temperatures.* FRANK PATTEN, GENE MCCORMICK,† AND WALTER GORDY, *Duke University.*—Electron spin resonances of CH_3, C_2H_5, and a number of other free radicals produced by irradiation of solids at room or liquid nitrogen temperatures have been observed at 4.2°K. Proton hyperfine structures of some of the resonances undergo qualitative changes as the temperature is lowered, whereas others do not. The changes depend markedly upon the nature of the medium in which the radicals are trapped. They are generally reversible, i.e., the original pattern of the resonance is restored when the temperature is again raised.

* This research was supported by the Office of Ordnance Research, Department of the Army, and by the U. S. Air Force.
† Now at The Texas Instrument Company.

FA8. Electron Spin Resonance in an X-Irradiated Single Crystal of Dimethylglyoxime.* ICHIRO MIYAGAWA AND WALTER GORDY, *Duke University.*—The electron spin resonance of free radicals produced by x-irradiation has been observed at 23 kMc/sec. A triplet hyperfine structure was observed which can be attributed to N^{14} nuclear coupling. Both the nuclear coupling A and the spectroscopic splitting factor g were found to be dependent upon the crystal orientation. The nuclear coupling is axially symmetric within the experimental error with the principal values of A, 45, 25, and 25 gauss. The sign of A could not be determined, but all the principal values have the same sign. The principal values of g are 2.003, 2.007, and 2.010, and the direction the minimum g is that of the maximum A. Calculations show that the anisotropy in A is due to the p character in the orbital of the unpaired electron. The s character of the orbital was estimated to be 20%.

* This research was supported by the Office of Ordnance Research, Department of the Army, and by the U. S. Air Force.

FA9. Effects of Absorbed Gases on Free Radical Resonances in Solids.* HARVEY REXROAD† AND WALTER GORDY, *Duke University.*—The effects of O_2 on the free radical resonance of x-irradiated Teflon reported earlier[1] has been further investigated. With samples having large surface area it was found that a strong new signal could be produced by the introduction of O_2 without a noticeable change in the resonance already produced by irradiation of the Teflon in vacuum. A similar effect was observed for NO. It is concluded that the paramagnetic O_2 and NO are trapped on or near the surface of the Teflon by ions or radicals which are produced by the irradiation and which do not themselves give an observable paramagnetic resonance. No such effects were observed for N_2, CO_2, and CO, although CO was found to reduce the signal observed for the trapped O_2. Ionized air was found to kill quickly the resonance of the trapped O_2.

* This research was supported by the U. S. Air Force.
† Now at the Department of Physics, University of West Virginia.
[1] Ard, Shields, and Gordy, J. Chem. Phys. 23, 1727 (1955).

FA10. Abstract withdrawn.

FA11. Electron Spin Lattice Relaxation Measurements of Cr^{3+} in Al_2O_3. H. R. LEWIS AND R. E. MICHEL, *RCA Laboratories.*—The X-band Zeeman spectrum of Cr^{3+} in Al_2O_3 has previously been given by Geusic[1] as a function of the angle θ between the c axis of the crystal and the static magnetic field. We have measured relaxation times for two $\Delta m_s=1$ and one $\Delta m_s=2$ transitions of the Cr^{3+} ion in the crystal as a function of θ, using the saturation method.[2] Measurements have been made at 300°K, 78°K, and 4.2°K and these indicate a temperature dependence which is much slower than present theory predicts.[3] The results add to a growing body of experimental data which suggests that the spin-lattice-bath relaxation process for paramagnetic resonance is not at present well understood.

[1] I. E. Geusic, Phys. Rev. 102, 1252 (1956).
[2] Bloembergen, Purcell, and Pound, Phys. Rev. 73, 679 (1948).
[3] M. Fierz, Physica 5, 433 (1938); R. Kronig, Physica 6, 33 (1939); J. H. Van Vleck, Physica 57, 427 (1939).

FA12. Paramagnetic Relaxation Times in $Gd_2Mg_3(NO_3)_{12}\cdot 24H_2O$.* G. FEHER, *Bell Telephone Laboratories.*—The variations between different crystals make it difficult to measure the concentration dependence of the observed spin-bath relaxation times. In some respects similar conditions may be simulated by measuring the relaxation time between various levels in the *same* crystal. In $Gd_2Mg_3(NO_3)_{12}\cdot 24H_2O$ at 1.2°K and 3000 oersteds the population ratio of the lowest to highest level is approximately 10. We find that the observed relaxation time T_1 is proportional to $1/N^m$, where $\frac{1}{2}<m<1$ and N is the population of the levels. The experiments were performed by the usual C.W. microwave saturation method. Lanthanum double nitrate crystals were used with a gado-

linium concentration ranging from 0.001 to 0.01 atomic percent. Measurements were performed with the magnetic field both parallel and perpendicular to the crystalline axis. The above results are in contradiction with the predictions of Giordmaine, Alsop, Nash, and Townes[1] based on the broadening of the lattice modes.[2] It is worth noting that their reported experimental results[1,2] on this salt can also be explained by the observed broad background resonance line which connects the different spins.

[1] Giordmaine, Alsop, Nash, and Townes, Phys. Rev. 109, 302 (1958).
[2] Nash, Giordmaine, Alsop, and Townes, Bull. Am. Phys. Soc. Ser. II, 3, 9 (1958).

FA13. Theory of Cyclotron Resonance by Ultrasound in Metals at Low Temperatures. T. KJELDAAS, JR., *Westinghouse Research Laboratories.*—The magnetic field dependence of the attenuation of transverse ultrasound (frequency ω, speed c_s) is calculated. The propagation vector $\mathbf{k}$ is along the magnetic field. Impurities are taken to determine the electron mean free path l and effective mass theory is used to describe the electronic motion. Our results are obtained by joint solution of the Boltzmann equation and Maxwell's equations. Substantial agreement with experiment[1,2] is obtained. When $kl \gg 1$ and for circularly polarized sound waves, the results can be interpreted physically as the juxtaposition of cyclotron resonances. The frequency of the electric field observed by the electron is $\omega(1+v_k c_s^{-1})$, where v_k is the electron velocity in the $\mathbf{k}$ direction. As the magnetic field is increased, electrons of specific v_k are brought into resonance. Thus in favorable cases quite detailed information regarding Fermi-surfaces should be obtainable. To decrease broadening, specimens of the highest purity should be used; the simple picture presented breaks down at too high frequency or magnetic field because of magneto-plasma resonance effects.

[1] H. E. Bommel, Phys. Rev. 100, 758 (1955).
[2] R. W. Morse, Bull. Am. Phys. Soc. Ser. II, 3, 44 (1958).

FA14. Crystal Field and Spin-Orbit Coupling Calculations for Ions with f^2 Configurations.* D. B. LEVINE AND C. M. HERZFELD, *National Bureau of Standards.*—The effects of a fourth degree octahedral crystal field and of spin-orbit coupling on the ^3H level of an ion with f^2 electron configuration were investigated. Eigenvalues and eigenvectors of the 33×33 matrix for the crystal field and spin-orbit energy were obtained numerically on the IBM 704 computer at National Bureau of Standards for eight values of D/ζ (D is the crystal field parameter and ζ the spin-orbit coupling constant of the free ion). The magnetic susceptibility of a powder was calculated as a function of temperature, for each value of D/ζ. The calculation was carried out for $\zeta=\infty$, 10^3 cm^{-1}, and 6×10^2 cm^{-1}. The results for the first value are given by the theory disregarding spin-orbit coupling, and the other two values of ζ bracket the most likely value for U^{+4} ions. The calculated magnetic susceptibilities are compared with some earlier measurements, and reasonable agreement is obtained.

* Supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.

FA15. Crystal-Field Theory of the Spectrum of O Atoms Trapped at 4°K.* H. GOLDBERG AND C. M. HERZFELD, *National Bureau of Standards and University of Maryland.*—Crystal-field perturbations of the ^3P, ^1D, and ^1S levels of the $2p^4$ configuration of O atoms have been calculated for O atoms trapped in lattices of O_3 and of N_2. The general model is used previously for the calculation of spectra of trapped N atoms.[1] The crystal field arising from the electric quadrupole moment of one molecule shifts and splits the unperturbed levels. Configuration interaction with $2p^33s$, produced by the crystal field, changes the probabilities for transitions between levels. The theoretical results are compared with the β lines observed in the emission spectra obtained during deposition of excited N atoms. These have previously[1] been ascribed to N atoms, but recently[2] interpreted as produced by O atoms. Adequate agreement is obtained between the theory for transitions in O atoms and the observed β lines. The absence of paramagnetic resonance absorption by trapped O atoms can also be explained.

* Supported by the U. S. Department of Defense through the Department of the Army.
[1] C. M. Herzfeld, Phys. Rev. 107, 1239 (1957).
[2] H. P. Broida and M. Peyron (to be published).

THURSDAY AFTERNOON AT 2:00

Sheraton-Park, Caribar-Mural Room

(M. G. WHITE presiding)

Accelerators II; Other Instrumentation

G1. Prompt Destruction of the Electron Beam in a Conventional Synchrotron. L. JACKSON LASLETT AND CHARLES L. HAMMER, *Iowa State College.**—The Hammer-Bureau[1] method for bringing a synchrotron beam onto a target has been examined computationally[2] and by an approximate analytic method. For an unperturbed field-index $n=0.6$, a 180-degree n-coil perturbs n to lie in the interval $0.7857<n<1.7096$. With a time-independent perturbation, the dominant unstable solution assumes the Floquet form $[\exp\mu\theta]F(\theta)$. The function $F(\theta)$ [period 4π] will be an *even* function of θ with its maxima near the center of the coil when operating near the first stability boundary. At larger n, the maxima (and nodes) shift to larger angles. By expressing $F(\theta)$ approximately in terms of eigensolutions which apply at the adjacent stability boundaries, expressions for μ and $F(\theta)$ are obtained. If n is a slowly increasing function, the solution of interest may be written $[\exp(\int\mu d\theta)]F(\theta)$, where $F(\theta)$ is only slightly modified by terms involving $dn/d\theta$. With $dn/d\theta$ small, n need not pass far beyond the first stability boundary before the desired amplitude growth is achieved, and the precession of the maxima accordingly will not be great.

* Aided by the U. S. Atomic Energy Commission.
[1] C. L. Hammer and A. J. Bureau, Rev. Sci. Instr. 26, 594, 598 (1955).
[2] Aided by the Midwestern Universities Research Association I.B.M.-704.

G2. Grid Focusing Studies in Cyclotron Central Region. H. G. BLOSSER AND F. IRWIN, *Oak Ridge National Laboratory.*—Grid structures have been placed in the ORNL 44-in. cyclotron in a manner which yields strong electrical vertical focusing at each accelerating gap without recourse to transit time effects. The grids are similar in principal to linear accelerator focusing grids, the entrant side of each dee being covered with a carbon structure which constitutes an essentially flat electrical surface. The cyclotron beam is initially

collimated to cut off out-of-phase particles, the radius gain for typical cyclotron operating conditions then being sufficient to allow programming turns, each successive turn passing through an individual slot in the grid. Studies have been made with protons in a flat magnetic field of 6400 gauss with dee to ground voltage 21 kv, these parameters yielding turn radii corresponding to those in a new ORNL cyclotron under construction. Beam currents of 3–4 ma have been programmed through five turns in a structure having two-inch vertical aperture, and with the resonant condition carefully maintained so as to eliminate transit time focusing effects. In the same conditions without grids 2–2.5 ma are obtained. Transition from grid focusing in the central region to subsequent magnetic focusing systems is in principle straightforward; experimental studies of this transition are in progress.

G3. Adiabatic Behavior of an Intense Relativistic Electron Beam Injected into Hydrogen-I. D. DEPACKH, *U. S. Naval Research Laboratory.*—It has been suggested[1] that an intense electron current could be used as the source of a guide field for ultra-relativistic protons. A possible source for such an electron current is an electron gun supplying about 1000 amp at 1 Mev. Since to create the necessarily high electric and magnetic fields to guide the accelerated protons the beam must be highly contracted, it is proposed to inject the electrons into a low density of hydrogen and then to accelerate them by betatron action. Equations governing the adiabatic contraction of such a beam are presented.

[1] G. J. Budker, CERN Symposium 1956, pp. 68–75.

G4. Adiabatic Behavior of an Intense Relativistic Electron Beam Injected into Hydrogen-II. T. F. GODLOVE AND D. DEPACKH, *U. S. Naval Research Laboratory.*—In the preceding abstract dePackh has given the equations of a high-current relativistic electron beam injected into hydrogen. These equations have been integrated under various assumptions with the aid of a digital differential analyzer. Typical parameters chosen for computation are as follows: injected electron current and energy: 1 kiloamp at 0.8 Mev; initial electron transverse energy: 0.3 to 2.0 ev; external strong focusing sufficient to give free betatron wavelength of 150 cm; calculated initial diam of beam under above conditions: 3.6 cm; forward electric field: 8.5 volts/cm. For an initial hydrogen density of 10^{14} cm^{-3}, the solution shows a collapse of the beam to a diam of 0.02 cm about 4 μsec after the injection pulse. This result is obtained under the simplifying assumption that the neutral atoms are stationary, and is the type of solution which will be studied experimentally, using a 250 amp, 360 kv gun from a Stanford klystron injecting into a straight pipe. For the eventual design of a circular multi-Bev proton accelerator, solutions will be shown in which the diffusion of hydrogen into the beam is included. This gives rise to continuous ionization and necessitates a much smaller initial H density, $\sim 10^{11}$ cm^{-3}, in order to achieve the desired end result of a smooth collapse to $\sim 10^{-3}$ cm diam in 1 msec.

G5. Properties of Intense Relativistic Electron Beams. RICHARD H. CAPPS, *University of Washington.*—A theoretical investigation has been made of intense, relativistic, partially neutralized, self-focusing electron beams. Budker and Enoch have shown how the parameters describing such a beam must be related if the beam radius and mean electron energy are constant in time.[1,2] In this "equilibrium" situation the increase in transverse electron momentum caused by scattering from the positive particles is compensated by radiative loss, and the energy lost by radiation is restored by an impressed, longitudinal electric field. Any reasonable scheme for the production of such a beam must allow time for radial shrinkage, since the equilibrium radii discussed by these authors are of the order 0.05 mm. We have derived approximate equations which express the time derivatives of the beam radius and mean electron energy as functions of these parameters, the electron and positive particle densities, and the impressed electric field. The time necessary for shrinking to the equilibrium radius is estimated, for reasonable values of the parameters.

[1] G. J. Budker, Proceedings of the CERN Symposium 1956, p. 68.
[2] J. Enoch, Midwestern Universities Research Association Report, MURA-311, 1957.

G6. Precision Integrator of Ion-Beam Current.* F. J. LYNCH AND A. LANGSDORF, JR., *Argonne National Laboratory.*—The current integrator for the electrostatic generator has given reliable and accurate service for eight years. An improved version has been constructed and tested. A vibrating-reed electrometer, without dc feedback, senses when an appropriate capacitor has been charged by the ion beam to potential of 10 standard cells in series. At that time it energizes relays which turn off counting circuits and a timer, discharge the capacitor, close the ion-beam shutter, etc. The electrometer sensitivity is about 0.1 mv the zero drift is less than 0.1 mv per day and the background current is less than 2×10^{-17} amp. Repeated measurements of the time constant for the discharge of the integrating capacitor through a precision resistor show a coefficient of variation of 0.0007%. This is the approximate accuracy of the crystal-controlled timer used. The important sources of error are (1) the time lag (~12 msec) in ending the integration, (2) soakage effects (<0.02%) in the polystyrene capacitors, and (3) the temperature coefficient of capacitance (about −0.01%/C°). It should be possible to control or correct for these systematic errors to reduce the total error to ~0.001%.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

G7. Fission Fragment Counting with Germanium *n-p* Junction Counters. F. J. WALTER,* J. W. T. DABBS, AND L. D. ROBERTS, *Oak Ridge National Laboratory.*—Broad area germanium *n-p* junction counters similar to those developed for alpha counting by Gossick and Mayer[1] have been used to detect alpha particles and fission fragments at 77°K and in the temperature region 1.3°–4.2°K. Counters with effective counting areas as large as 1 cm^2 have shown good resolution and reasonable stability. Under optimum conditions, a resolution of 4%, full width at half maximum, has been obtained for 4.8 Mev alpha particles. Preliminary results suggest that the response of these counters is approximately linear with particle energy up to the highest energies of fission fragments. A curve of the counting rate as a function of energy for U^{233} fission fragments (taken at 4.2°K) clearly shows two peaks and is similar to the curve for U^{235} fission fragments obtained by Brunton and Hanna[2] using a gas counter.

* Introduced by L. D. Roberts.
[1] B. Gossick and J. Mayer, Rev. Sci. Instr. 27, 407–408 (1956).
[2] D. C. Brunton and G. C. Hanna, Can. J. Research A28, 190–227 (1950).

G8. Nuclear Emulsion Scanner for Nuclear Spectroscopy.* P. V. C. HOUGH, W. WILLIAMS, AND R. O. WINDER, *University of Michigan.*—A machine has been constructed which will for a useful class of problems replace human observers in the counting of proton tracks in NTB emulsion. The machine scans 1×8 in. of emulsion per hour with an efficiency of about 90% and an error rate of about 25/cm^2. In scanning plates exposed at the image plane of the analyzer magnet of the 42 in. cyclotron, the integrated number of tracks in a group must exceed about 20 for reliable detection.

* Supported by the Michigan Memorial Phoenix Project and by the U. S. Atomic Energy Commission.

G9. Finite Source Considerations for the Spherical Condenser Spectrometer. R. D. BIRKHOFF AND R. H. RITCHIE, *Oak Ridge National Laboratory.*—The performance of the spectrometer described previously[1] has been evaluated

theoretically in the small angle approximation for sources of finite size. Line profiles have been obtained for point sources on the surface of the inner sphere, but displaced from the axis of symmetry, and these may be combined to yield line profiles for disk sources. The transmission and resolution are found to depend only slightly on the source size. For example, for an inner sphere radius of 10 cm, and an angle ϕ of 120°, a source 6.3 cm in diameter gives an average transmission of 19.2% at an energy resolution of 8.5%. The luminosity (product of transmission and source area) is 6.0 cm². For an angle ϕ of 170°, a source 1 cm in diameter gives an average transmission of 3.2% at an energy resolution of 0.25%. The luminosity is 0.028 cm².

[1] Birkhoff, Ritchie, and Cheka, Bull. Am. Phys. Soc. Ser. II, 2, 174 (1957).

G10. A Fast Sodium-Iodide (NaI) Spectrometer and Its Application to Millimicrosecond Time Measurement.* L. E. BEGHIAN, G. H. R. KEGEL, AND R. P. SCHARENBERG, *M.I.T.*—Unactivated sodium iodide cooled to liquid nitrogen temperature can be used as a fast scintillator.[1] A practical scintillation counter, using a cooled unactivated NaI phosphor, has been constructed for detecting low-energy gamma rays. The energy resolution is comparable to that obtained with NaI(Tl). The fluorescence decay time is of the order of 10^{-8} sec. The counter can be used to measure the time interval between the emission of two low-energy gamma quanta, in the millimicrosecond interval. The associated electronic equipment includes a delay-to-pulse-height converter, with an inherent time resolution of 10^{-10} sec. The entire system was tested by detecting the annihilation quanta from a Na^{22} source. An over-all resolving time of $2\tau_0 = 2.7 \times 10^{-9}$ sec was obtained.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. Van Sciver, Proc. Inst. Radio Engrs. NS-3 (1956).

G11. Initial Performance of a Precision Solenoidal Beta-Ray Spectrometer.* C. G. PATTEN, M. E. GARDNER, J. A. JUNGERMAN, AND P. G. LICHTENSTEIN, *University of California, Davis.*—A beta-ray spectrometer using an end-corrected iron-free solenoid has been constructed. Nuclear magnetic resonance field measurements along the electron trajectories indicate a contribution of less than one part in ten thousand in line width due to field inhomogeneity. Initial measurements of the spectrum of thorium *B* active deposit will be discussed.

* Work supported in part by the U. S. Atomic Energy Commission.

G12. Direct Reading Resistance Thermometer. H. PRESTON-THOMAS AND T. M. DAUPHINEE, *National Research Council, Canada.*—The use of an isolating potential comparator allows us to make precise resistance thermometer measurements even when leads several thousand feet long are involved. Since a considerable increase in utility and convenience results when such measurements read out in degrees instead of ohms, an instrument to do this was designed and built covering the range −50°C to 711°C in steps of 0.001°C with provision for presenting the last two or three figures on a recording potentiometer. The circuit essentially converts a quadratic (except for the quadratic region below 0°C) signal to a linear one. In order to accommodate any standard platinum resistance thermometer the three constants of the quartic must be adjustable, two of them being independent of the settings of the others. These adjustments and the switch resistances must not contribute resistance errors greater than four parts per million, and intrusive thermal emf must be reduced to the order of two tenths of a microvolt. The circuit finally selected to fulfil these rather severe requirements employs standard twelve position switches for the lower five decades with plugs for the 100°C steps. Linear resistance trains are used and the circuit can be auto calibrated. The whole instrument is approximately the size of a standard Mueller bridge.

G13. Boltzmann Equation and the Ionic Centrifuge. J. SLEPIAN, *Pittsburgh, Pennsylvania.*—Three Americans have written a stimulating paper[1] attempting to show the equivalence of the one-fluid hydromagnetic equation and the Boltzmann equation without collisions. They expand the Boltzmann equation in powers of M/e, $f = f_0 + f_1 + f_2$—and then get $(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \text{grad}_{\mathbf{v}} f_0 = 0$ (3); $[(\partial/\partial t) + \mathbf{v} \cdot \text{grad}] f_0 + (e/M)(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \text{grad}_{\mathbf{v}} f_1 = 0$ (4); ···. They say that for the positive ions a set f_0^i, f_1^i, f_2^i ··· is necessary, and they carry out the process for f_0^i and f_1^i; for electrons the drifts for higher than f_0^e can be completely ignored. We have found this approximation extremely valuable for the Magneto-Ionic Expander.[2] For the Ionic Centrifuge,[3,4] however, higher terms than f_0^e are necessary. This is because of the fact that $n_0^e \mathbf{u}^e = \int d\mathbf{v} \mathbf{v}^e f_0^e$ is so small compared to the effective range of $n_0^e \mathbf{v}^e$ that we cannot neglect higher orders of f_0^e, such as f_1^e.

[1] Chew, Goldberger, and Low, Proc. Roy. Soc. (London) A236, 112–118 (1956).
[2] J. Slepian, J. Franklin Inst. 263, 129–139 (1957).
[3] J. Slepian, J. Appl. Phys. 26, 1283 (1955).
[4] J. Slepian, Nuclear Sci. and Eng. (1958).

THURSDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(E. M. MCMILLAN presiding)

Invited Papers

GA1. Decay of Positronium in Solids and Liquids. R. E. BELL, *McGill University.* (30 min.)

GA2. Proton-Nucleus Elastic Scattering. N. M. HINTZ, *University of Minnesota.* (30 min.)

GA3. High-Resolution Gamma-Ray Spectra from Coulomb Excitation. HANS MARK, *University of California, Livermore.* (30 min.)

GA4. Reactions in Light Nuclei Induced by Helium-3. D. A. BROMLEY, *Chalk River Laboratories.* (30 min.)

THURSDAY AFTERNOON AT 2:00

NBS, Materials Testing Building

(E. P. WIGNER presiding)

Theoretical Physics II, Including Nuclear Forces

H1. Modified Boundary Condition Model of the Nucleon-Nucleon Interaction. E. LOMON, *McGill University.*—A semiquantitative fit to the nucleon-nucleon data has been given by the simple boundary condition model.[1] The recent experiments at 310 Mev have a phase shift solution of the type predicted by the model.[2] The boundary condition was modified by the addition of a potential tail in the hope of obtaining good quantitative fits with a simpler model than the complicated potentials required.[3] The effect of this tail is strongest at low energies. The effect on s states has been treated analytically,[4] and approximate methods applied for higher angular momenta. Work is in progress to find the best over-all fit with simple tails.

[1] H. Feshbach and E. Lomon, Phys. Rev. **102**, 891 (1956).
[2] Stapp, Ypsilantis, and Metropolis, Phys. Rev. **105**, 302 (1957). See Solution 6. The suitable isotopic singlet phase shifts also correspond to the boundary condition model.
[3] J. L. Gammel and R. M. Thaler, Phys. Rev. **107**, 1337 (1957). Further references will be found here.
[4] In collaboration with M. Nauenberg.

H2. Singlet-Even and Triplet-Even Gartenhaus Potential Range Parameters.* C. R. FISCHER, K. D. PYATT, JR., M. H. HULL, JR., AND G. BREIT, *Yale University.*—The Marshak-Signell[1] modification of the Gartenhaus potential has been studied at low energies. From p-p data in the range 0–5 Mev it is concluded that the range parameter must be increased by about 15%. The increase in range is in approximate agreement with the new Minnesota data at 9.74 and 39.58 Mev. The triplet even interaction with and without the spin-orbit term fits low-energy scattering data which speak against a range parameter change comparable with that indicated by low-energy p-p data for singlet even states. These inconsistencies and those noted by Marshak and Signell support the view that the potential has qualitative significance only.

* This research was supported by the Office of Ordnance Research, U. S. Army and by the U. S. Atomic Energy Commission.
[1] P. S. Signell and R. E. Marshak, Phys. Rev. **106**, 832 (1957) and NYO-2100.

H3. Features of Nucleon-Nucleon Interactions Suggested by a Static Model.* G. BREIT, *Yale University.*—On the basis of a static model of *PSps* interactions[1] it appears reasonable to expect the following effects. Spin-orbit forces differing in magnitude and shape for odd and even states. Approximate but not exact applicability of the e^2/r Coulomb potential in p-p and p-n comparisons. The occurrence of a quadratic effect of a tensor interaction when the equation is reduced to a form involving effective potentials. Velocity dependence of effective potentials appearing in effective potentials for radial wave functions. Dependence of core radii on energy. Automatic appearance of cores. The equation furnishes tensor interactions with momentum replacing coordinate. The model has no quantitatively accurate significance as is clear from its crude character and derivation but it appears to agree with some qualitative indications of recent phenomenologic fits of Marshak and Signell and of Gammel and Thaler.

* This research was supported by the Office of Ordnance Research, U. S. Army and by the U. S. Atomic Energy Commission.
[1] G. Breit, *Proceedings Sixth Rochester Conference* (April, 1956).

H4. Spin-Orbit Coupling in Nucleon Scattering from an Isobar Model.* R. B. RAPHAEL, *University of Pennsylvania.*—It is believed that the failure of previous attempts to understand high energy nucleon scattering in terms of nucleon isobars was not caused by any basic inadequacy of the isobar mechanism, but rather by the shortcomings of the specific form of interaction used; e.g., neglect of spin-orbit coupling. In support of this contention, a phenomenological theory has been constructed, along lines previously suggested,[1] employing static tensor interactions which stimulate transitions to excited (3/2, 3/2) states of the nucleons. These virtual excitations result in an effective odd-state spin-orbit coupling in agreement with the recent Gammel-Thaler[2] (GT) fit of scattering data below 300 Mev, provided that one assumes the GT tensor interaction in the ground state. With this choice, no other significant modifications of the ground-state interaction occur. The theory contains a single "excitation" parameter, which may in principle be calculated from meson theory. Thus the observed spin-orbit force and its attendant polarization effects may be viewed as a consequence of isobaric coupling.

* Supported in part by the National Science Foundation.
[1] R. B. Raphael and J. Schwinger, Phys. Rev. **90**, 373(A) (1953).
[2] J. L. Gammel and R. M. Thaler, Phys. Rev. (to be published).

H5. Nuclear Spin-Orbit Interaction. B. P. NIGAM AND M. K. SUNDARESAN, *National Research Council, Canada.*—Following Brueckner's[1] theory of nuclear structure, the tensor force of the two-body interaction has been used to estimate the spin-orbit interaction of a single nucleon interacting with the core. Using Yamaguchi's[2] separable two-body interaction, the doublet splitting for Ca^{41} and O^{17} have been calculated (i) in the first Born approximation and (ii) with an exact solution of the reaction matrix in which the exclusion principle has been taken into account. It is found that the magnitude of the splittings calculated exactly are smaller than the experimental values.

[1] K. A. Brueckner, Phys. Rev. **97**, 1344, 1353 (1955).
[2] Y. Yamaguchi, Phys. Rev. **95**, 1635 (1954).

H6. Unified Theory of Nuclear Reactions. HERMAN FESHBACH, *M.I.T.*—A formalism for nuclear reactions is developed in which resonance phenomena and "direct" effects appear simultaneously in the scattering amplitude. The expressions obtained for the widths for both elastic and inelastic scattering show directly a single-particle giant resonance effect. The cloudy crystal ball potential may be obtained by asking what potential will give rise to the energy average scattering amplitude. The statistical hypothesis was not employed nor was any statement about (Γ/D) required. A similar potential is obtained to describe inelastic and charge exchange scattering. The high-energy limit as well as some conditions on the validity of the statistical hypothesis are considered. The limitations on the formalism will be discussed.

H7. Resonance Cross Sections of Fissionable Nuclei. E. VOGT, *Atomic Energy of Canada Limited* (introduced by G. E. Lee-Whiting).—The general Wigner-Eisenbud theory is used to develop a method of analysis for the cross sections of fissionable nuclei. The method is employed in giving a reasonable description of the low-energy cross sections in U^{233}. The single level fit for U^{235} is known to be unreasonable. Many-level expressions for the cross sections are derived—the only approximation to the general theory being the neglect of all but a small group of resonances. It is shown that regardless of the number of definition of the fission channels

the many-level expressions require few level parameters: the E_λ, $\Gamma_{\lambda n}$, $\Gamma_{\lambda\gamma}$, and $\Gamma_{\lambda f}$ of the single level theory for each resonance and a few additional parameters pertinent to the interference between levels. The interference terms are described and shown to be important. The shape and size of the U^{235} cross sections below 2 ev are fitted to within 1% using: (a) only one negative energy resonance of smaller size than in the single level fit; (b) no additional levels to fit the shape other than the observed levels at positive energies; (c) three interference parameters whose size suggests that there are several fission channels in U^{235}.

H8. Higher Order Contributions of Scalar and Pseudoscalar Mesons to Nucleon Magnetic Moments.* C. B. SHAW, JR.,† AND R. E. F. THOMPSON, *University of Southern California.*—Nakabayasi and co-workers[1] computed nucleon anomalous magnetic moments up to fourth order in the coupling constant between the nucleon and the pseudoscalar meson fields, for purely charged, charge-symmetric, and excess-neutral meson fields. Agreement with experiment was markedly improved with each addition of neutral mesons. Our calculations, also to fourth order, assume the meson field to consist of the usual charge-symmetric pseudoscalar mixture, (an isotopic-spin triplet,) plus a neutral *scalar* meson field (isotopic-spin singlet). With two parameters to adjust, we can reproduce both magnetic moments. Numerical evaluation of the necessary matrix elements shows, however, that if we restrict ourselves to the generally accepted range of values for the pseudoscalar coupling constant the addition of any neutral scalar pion field cannot improve the agreement between theory and experiment.

* Partially supported by Hughes Aircraft Company.
† Now at Hughes Aircraft Company.
[1] K. Nakabayasi and I. Sato, Sci. Repts. Tôhoku Univ., First Ser. 34, I, No. 4 (1950); Progr. Theoret. Phys. (Kyoto) 6, 252 (1951); Nakabayasi, Sato, and Akiba, *ibid.* 12, 250(L) (1954).

H9. Nuclear Effects in Internal Conversion.* E. L. CHURCH,† *Frankford Arsenal,* AND J. WENESER, *Brookhaven National Laboratory.*—The current interest in precise measurements of internal-conversion coefficients has prompted us to investigate the possible dependences of such coefficients on details of the atomic-nuclear system. Since conversion "occurs" in the vicinity of the nucleus, we have first investigated those perturbations which might distort the electron wave functions at small distances. The effects on the K-shell wave functions of a large nuclear distortion, and the related static nuclear electric-quadrupole and magnetic-dipole moments, have been estimated. These results have been applied to the calculation of the K conversion of nuclear transitions leading to a spin zero state, and the effects found to be very small. Electrodynamic corrections to the Dirac equation have been considered as well. The present results also have application to other processes, such as electron capture.

* Under the auspices of the U. S. Atomic Energy Commission.
† Guest Scientists, Brookhaven National Laboratory, Upton, New York.

H10. High-Energy Electron Bremsstrahlung from an Extended Proton. D. MOROI, M. DRESDEN, AND T. FULTON, *The Johns Hopkins University.*—A calculation has been made of the energy and angular distribution of electrons and photons arising from the bremsstrahlung of high-energy electrons on an extended proton. The form factors describing the charge and current distribution of the proton are the ones used in the interpretation of the Stanford experiments on the elastic scattering of electrons on protons. The calculation is patterned after the usual bremsstrahlung calculation, and uses the Born approximation. As might be anticipated, the main effect of the extended charge and current, as contrasted with the point charge, is to be found in the distribution of those electrons and photons which are scattered through an appreciable angle with respect to the initial momentum direction. From these distributions, it is in principle possible to obtain independently both the complete charge and the complete current form factors. It is believed that the use of the Born approximation is justified, particularly since the main effect is important for large angles only. The influence of processes such as electron-electron bremsstrahlung, exchange terms, and nuclear recoil, can be computed and must be taken into account to obtain information about the form factors from the bremsstrahlung spectrum.

H11. Higher Order Approximations in Multiple Scattering.* N. R. ZITRON AND S. N. KARP, *New York University* (introduced by S. Borowitz).—It has been shown[1] that for two sufficiently widely spaced scatterers a first-order correction for multiple scattering can be obtained by regarding each scatterer as being under the influence of (a) the incident field, and (b) a plane wave arriving from the other scatterer; the correction was given explicitly in terms of the complex scattering amplitudes of the individual scatterers. The present work contains higher order approximations of this type. It is shown that the higher order terms can be expressed in terms of the derivatives of the individual scattering amplitudes. Terms of order d^{-3}, d^{-4}, and d^{-5} have been calculated explicitly. (Here d is the spacing.) The procedure can be conveniently extended to the case of more than two scatterers.

* Research supported in part by the Air Force Cambridge Research Center, Air Research and Development Command.
[1] S. Karp, Phys. Rev. 86, 586(A) (1952), and Symposium of Electromagnetic Theory, McGill University, Montreal, Canada, June, 1953.

H12. Linear Approximation Treatment of Spherical Gravitational Waves.* JOHN BOARDMAN AND PETER G. BERGMANN, *Syracuse University.*—Einstein and Rosen[1] have constructed rigorous solutions of the field equations of general relativity, obtaining gravitational waves possessing cylindrical symmetry. It has recently been established by Rosen and Weber[2] that these waves carry no energy flux. No rigorous solution has yet been obtained for the more interesting case of gravitational waves possessing spherical symmetry. However, a linear approximation indicates that such waves do carry energy flux. For the calculations we have employed "hyperpotentials," whose second derivatives are the gravitational potentials. For the flux of energy at spatial infinity we have calculated, for each possible type of symmetry, the leading $(1/r)$ terms in the gravitational field strengths and used them in the Poynting's vector associated with the so-called canonical energy-stress complex. As is to be expected, the conservation laws can be satisfied only if the lowest physically meaningful gravitational radiation is quadrupole radiation. For a check on the validity of this approximation procedure, we have carried out the analogous calculation for cylindrical waves, where a rigorous solution is also available.

* Research supported by Aeronautical Research Laboratory, WADC.
[1] Einstein and Rosen, J. Franklin Inst. 223, 43 (1937).
[2] Rosen, Helv. Phys. Acta, Suppl. IV, 171 (1955); Weber, *Report of Conference on the Role of Gravitation in Physics* (Chapel Hill, North Carolina, 1957), p. 37.

H13. Stable Orbits of Charged Particles in an Oscillating Electromagnetic Field. ERICH S. WEIBEL, *The Ramo-Wooldridge Corporation.*—Orbits in a field of the cylindrical wave guide driven in the TE_{01} mode have been studied. The radial components of the Lorentz force acting on the particle is never positive regardless of its charge, thus it is attracted toward the axis of the wave guide around which it moves in a complicated path. Sufficient conditions are given under which the orbits are stable that is, remain bounded for all times. In general it is found that particles are always attracted toward the nearest node of the electric field.

H14. General Formulation for Missile Powered Flight Trajectory Optimization Problems. BURTON D. FRIED, *The Ramo-Wooldridge Corporation.*—Let $\{\xi_i\}$ denote the values of $\mathbf{r}$ (position), $\partial\mathbf{r}/\partial t$ (velocity), and M (mass) evaluated at the beginning and end of powered flight. Many optimization problems consist in making some function, W_0, of the ξ_i stationary while holding constant certain other functions, $W_1 \cdots W_m$, of the ξ_i. For a point particle missile, the vector $\boldsymbol{\lambda}(t)$ specifying optimum thrust direction satisfies

$$(\partial^2\boldsymbol{\lambda}/\partial t^2) - \nabla_v\boldsymbol{\alpha}\cdot\boldsymbol{\lambda} + (d/dt)(\nabla_v\boldsymbol{\alpha}\cdot\boldsymbol{\lambda}) = 0,$$

where $\boldsymbol{\alpha}$ is the nonthrust acceleration. The optimum $M(t)$ satisfies

$$\lambda(\partial M/\partial t)c/M^2 + \frac{d}{dt}\left[\lambda\left(c/M + \frac{\partial M/\partial t}{M}\frac{\partial c}{\partial(\partial M/\partial t)}\right)\right] - \boldsymbol{\lambda}\cdot\partial\boldsymbol{\alpha}/\partial M = 0.$$

(Exhaust velocity, c, is assumed to be a known function of M and t.) While the boundary conditions vary with the choice of $W_0 \cdots W_m$, one finds always the above differential equations which, together with $\partial\mathbf{r}/\partial t = -(\partial M/\partial t)c\boldsymbol{\lambda}/M\lambda + \boldsymbol{\alpha}$, constitute a coupled system. Some examples which permit analytic solutions in closed form will be cited.

FRIDAY MORNING AT 9:15

Sheraton-Park, Continental Room

(SIDNEY MILLMAN presiding)

Atomic-Beam Experiments

J1. Atomic Beam Double Resonance.* G. O. BRINK, N. BRASLAU, AND J. M. KHAN, *University of California, Berkeley.*—Transitions that are not otherwise observable in an atomic beam flop-in apparatus have been observed by means of a double resonance technique. The method has been used to observe the $\Delta F = 0$ transitions in K^{39}, and involves the use of three rf hairpins through which the beam passes in succession. The frequency of the rf in the first and third hairpins is adjusted to produce the transition $(2,-1)\leftrightarrow(1,-1)$. If an atom enters the transition region in the state $(2,-1)$ it will go to $(1,-1)$ in the first hairpin and then back to $(2,-1)$ in the third. Thus a small signal will be seen at the detector. If the transition $(1,-1)\leftrightarrow(1,0)$ is excited in the second hairpin, some of the atoms that have gone from $(2,-1)$ to $(1,-1)$ will go to $(1,0)$ and will not go back to $(2,-1)$ in the third hairpin. An increase in detector reading will thus be seen when the transition $(1,-1)\leftrightarrow(1,0)$ is excited. The other $\Delta F = 0$ transitions can also be observed by choosing the proper $\Delta F = \pm 1$ transition. This technique will be used to measure nuclear magnetic moments.

* Supported by the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

J2. Frequency Shift of the Zero Field Hyperfine Splitting of Cs^{133} Produced by Various Buffer Gases. M. ARDITI, *Federal Telecommunication Laboratories* (introduced by T. R. Carver).—Investigations of the frequency shift produced by argon and neon buffer gases in the zero field hyperfine splitting of Na^{23} have been previously reported.[1] This note gives the results of similar experiments performed with Cs^{133}. Using the (4,0) to (3,0) microwave transition with optical pumping and optical detection, the value of the hyperfine splitting of cesium in the ground state was found to be: 9192.632 10^{-6} sec^{-1} ± 500 cycles, in agreement with the value given by atomic beam measurements.[2] The effect of buffer gas pressure in shifting the hyperfine frequency was studied using gas pressures from 1 to 15 mm Hg. A pressure shift to higher frequency was found in the case of the lighter rare gases helium and neon while a pressure shift to lower frequency was found in the case of the heavier gases argon, krypton, and xenon. These pressure shifts may be as large as several kc/mm in certain cases. These results suggest pressure shifts for the hyperfine transition quite similar to optical pressure shifts and line asymmetry of alkali metal resonance radiation in rare gas,[3] instead of resonance exchange effects as previously suggested.[1]

[1] M. Arditi and T. R. Carver (to be published).
[2] L. Essen and J. V. L. Parry, Nature 176, 280 (1955).
[3] O. Oldenberg, Z. Physik 55, 1 (1929).

J3. Optical Detection of the Cesium Hyperfine Splitting.* EARL C. BEATY AND PETER L. BENDER, *National Bureau of Standards.*—The (4,0)→(3,0) hyperfine transition in cesium near 9192 mc has been detected optically using hyperfine pumping, and pressure shifts in various buffer gases have been measured. Cs vapor diffusing in a buffer gas was irradiated with light having different intensities at the 8521.0 and 8521.2 A hyperfine components of the Cs $6S_{\frac{1}{2}}\rightarrow 6P_{\frac{1}{2}}$ absorption line, causing pumping from one $6S_{\frac{1}{2}}$ hyperfine level into the other. Absorption of microwaves of the proper frequency (~9192 mc) is detected by an increase in the scattered light. Two light sources have been used successfully. The one with which most of the pressure shifts were measured was a Cs discharge followed by a Cs absorption cell to produce the desired difference in intensity.[1] Recently better signals were obtained with an argon discharge for which the 8521.4 A line was Zeeman split to overlap the Cs 8521.2 A component. The pressure shifts measured were +1200, +900, +580, −220, and −800 cy/mm for He, N_2, Ne, Ar, and Kr. Line widths will be discussed.

* The work was largely performed at the U. S. Naval Research Laboratory, using the unique precision frequency facilities of the Radio Techniques Branch.
[1] The mechanism here is the same as that used for sodium by Arditi and Carver and by Bloom and Bell.

J4. Magnetic Dipole Moment of Au^{191}.* W. B. EWBANK, L. L. MARINO, W. A. NIERENBERG,† H. A. SHUGART, AND H. B. SILSBEE, *University of California, Berkeley.*—Measurements on the $\Delta F = 1$ transitions in 4.8-hour Au^{192} have further confirmed its unexpectedly small nuclear magnetic moment, a preliminary report of which has been given before.[1] The atomic beam apparatus and method of radioactive detection have also been described previously.[2] Observations on the transition $(F=\frac{3}{2}, m_F=-\frac{1}{2})\leftrightarrow(F=\frac{3}{2}, m_F=-\frac{3}{2})$ at several values of the transition magnetic field up to 75.5 gauss made possible the search for the direct transitions $(F=\frac{3}{2}, m_F=\frac{1}{2})\leftrightarrow(F=\frac{1}{2}, m_F=-\frac{1}{2})$ and $(F=\frac{3}{2}, m_F=-\frac{1}{2})\leftrightarrow(F=\frac{1}{2}, m_F\frac{1}{2})$ at low fields. The frequencies of these two transitions differ by a very small term, $2g_I\mu_0 H/h$, and consequently they have not been resolved. Measurement of the frequency of this doublet at transition fields of 8.4 and 9.4 gauss established both the identity of the line and the zero-field hyperfine structure separation. The best value at present is: $\Delta\nu = 374.3 \pm 0.2$ Mc/sec, which, together with previous measurements[3] on stable Au^{197} and the Fermi-Segrè formula gives a magnetic moment of $|\mu| = 0.0076 \pm 0.0011$ nuclear magneton. The size

of the moment makes a sign determination impossible with the present apparatus.

* This research was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
† At present Professor in the Miller Institute for Basic Research in Science.
[1] Ewbank, Marino, Shugart, and Silsbee, Bull. Am. Phys. Soc. Ser. II, 2, 383 (1957).
[2] Hobson, Hubbs, Nierenberg, Silsbee, and Sunderland, Phys. Rev. 104, 101 (1956).
[3] G. Wessel and H. Lew, Phys. Rev. 92, 641 (1953).

J5. Molecular Beam Studies of Metastable States of Mercury. WILLIAM LICHTEN AND MARK MCDERMOTT, *Columbia University.*—The atomic beam magnetic resonance method is being applied to measurements of the properties of the metastable electronic states of mercury. A beam of mercury atoms in the ground state is subjected to electron bombardment. A fraction of the atoms are excited to metastable states. All atoms are refocused upon a stop wire by the A and B deflecting magnets. Atoms undergoing a transition in the C region are defocused and strike a sodium coated secondary emission detector. The transitions $\Delta F=0$, $\Delta m_F=\pm 1$ have been observed for the even isotopes and for all the hyperfine levels of the odd isotopes of mercury in the $(6s, 6p)^3P_2$ state. In particular, the signal to noise ratio in ths single transition Hg^{201}, $F=\frac{1}{2}$, $\Delta m_F=\pm\frac{1}{2}$, indicates that measurements of the hfs are feasible. These measurements are in progress. Transitions $\Delta F=0$, $\Delta m_F=\pm 1$ have been observed for another metastable state of mercury lying at higher energy, with $J=3$, $g_J=1.09\pm 0.02$. These observations confirm an earlier report[1] which indicated that the $(5d)^9(6s)^2\,6p\,{}^3D_3$ state is metastable.

[1] William Lichten, Phys. Rev. 109, 1191 (1958).

J6. Nuclear Spins of Tl^{200} and Tl^{201}.* LAWRENCE L. MARINO, GILBERT O. BRINK, WESLEY B. EWBANK, H. A. SHUGART, AND HENRY B. SILSBEE, *University of California, Berkeley.*—The nuclear spins of 27-hour Tl^{200} and 3.0-day Tl^{201} have been measured by an atomic-beam magnetic-resonance flop-in technique using radioactive detection.[1] The value $I=2$ was measured for Tl^{200} by observing the $^2P_{\frac{1}{2}}$, $F=\frac{5}{2}$, $m_F=-\frac{5}{2}\leftrightarrow m_F=-\frac{3}{2}$ transition at 2.4 and 3.5 Mc/sec. The value $I=\frac{1}{2}$ was measured for Tl^{201} by observing the $^2P_{\frac{1}{2}}$, $F=1$, $m_F=0\leftrightarrow m_F=-1$ transition at 6.1 and 8.7 Mc/sec. The isotopes were prepared by the $Hg(d,kn)Tl$ reaction with 24-Mev deuterons from the 60-inch Berkeley cyclotron. Separation of the thallium from the mercury target was accomplished by distillation. Thallium atoms passing through the apparatus were collected on sulfur-coated surfaces and detected by counting k x-rays following electron capture. The measurement $I=\frac{1}{2}$ for Tl^{201} is consistent with an $s_{\frac{1}{2}}$ proton assignment as in Tl^{197},[2] Tl^{199},[2] Tl^{203}, and Tl^{205}. The spin of Tl^{200} is the same as that of Tl^{204}.[2]

* This research was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Hobson, Hubbs, Nierenberg, Silsbee, and Sunderland, Phys. Rev. 104, 101 (1956).
[2] Brink, Hubbs, Nierenberg, and Worcester, Phys. Rev. 107, 189 (1957).

J7. Nuclear Spin of Neptunium-238.* R. MARRUS, R. G. ALBRIDGE, AND J. C. HUBBS. *University of California, Berkeley.*—An atomic-beam magnetic resonance experiment performed to determine the ground-state nuclear angular momentum of neptunium-238 yields the result $I=2$. Production of the material is via the reaction $Np^{237}(n,\gamma)Np^{238}$ which proceeds with a cross section of 170 barns. Observations are made on the $J=11/2$, $g_J=0.6551$ electronic state of neptunium previously reported in work on neptunium-239.[1] Resonances are observed for four of the five possible flop-in transitions in this state. The fifth, which is seen with a probability of about two to one, is highly discriminated against by apparatus selection rules. These resonances are observed in the Zeeman region of hyperfine structure at a field of 13.4 gauss. The identity of the material is inferred from its method of production and from an observed half-life of 2.1 days. The measured value of I is consistent with the observed beta decay of neptunium-238.[2]

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] J. C. Hubbs and R. Marrus, Phys. Rev. (to be published).
[2] Rasmussen, Slätis, and Passell, Phys. Rev. 99, 42 (1955); Rasmussen, Stephens, Strominger, and Astrom, *ibid.* 99, 47 (1955); S. A. Baranov and K. N. Shlyagin, Atomnaya Energ. 1, 52 (1956); R. G. Albridge and J. M. Hollander, "The Decay of Neptunium-238," UCRL-8034, November, 1957.

J8. Collective Model Interpretation of Odd-Odd Nuclear Magnetic Moments.* WILLIAM M. HOOKE, *Princeton University.*—In order to interpret the observed spin and magnetic moment of Au^{196},[1,2] we have extended to odd-odd nuclei the collective model calculation of nuclear magnetic moments. Nilsson's[3] results for the wave functions and energy levels of a particle moving in a nonspherical potential have been used. Two coupling schemes differing in the relative strength of the odd neutron-odd proton interaction will be discussed and compared with experimental results for several odd-odd nuclei in addition to those of the gold isotopes.[1,2,4]

* This work was supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] Reynolds *et al.*, Bull. Am. Phys. Soc. Ser. II, 2, 317 (1957).
[2] Hooke, Christensen, Hamilton, Reynolds, and Stroke, Bull. Am. Phys. Soc. Ser. II, 2, 344 (1957).
[3] Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 29, No. 16 (1955).
[4] Ewbank, Marino, Shugart, and Silsbee, Bull. Am. Phys. Soc. Ser. II, 2, 383 (1957).

Invited Papers

J9. A Free Precession Determination of the Proton Gyromagnetic Ratio. P. L. BENDER, *National Bureau of Standards.* (30 min.)

J10. The Microtron as a High-Energy, High-Current Accelerator. ARTHUR ROBERTS, *University of Rochester.* (30 min.)

FRIDAY MORNING AT 9:15

Sheraton-Park, Caribar-Mural Room

(R. SHERR presiding)

Nuclear Reactions I

K1. Angular Distributions for (He^3,p) Reactions. D. R. SWEETMAN,* *A.W.R.E., Aldermaston, England.*—The angular distributions of proton groups resulting from the interaction of 6.05-Mev He^3 ions with Be^9, B^{10}, B^{11}, and C^{12} have been investigated using the 6-Mev Van de Graaff generator at A.W.R.E., Aldermaston. The distributions for low energies

of excitation in the final nucleus resemble those obtained at lower incident beam energies by other workers except that there are strong maxima in the forward direction for most of the levels investigated, indicating that direct interaction processes may be playing an important role at this energy. For levels at higher excitation energies of the final nucleus, the distributions become complicated, though they still retain forward maxima. The possibility of utilizing the angular distributions from He^3 reactions for the determination of nuclear spins will be discussed.

* At present on sabbatical leave as a Commonwealth Fund Fellow to the United States.

K2. Cross Section for the Reaction $Li^6(n,t)He^4$ from 12.5 to 18.3 Mev. B. D. KERN* AND W. E. KREGER, *U. S. Naval Radiological Defense Laboratory.*—The intensity *vs* pulse height curve of a $Li^6I(Eu)$ scintillation crystal exhibits a broad but distinct peak as a result of the $Li^6(n,t)He^4$ reaction.[1] The response of a ½-inch thick×1½-inch diameter $Li^6I(Eu)$ crystal has been obtained for 12.5- to 18.3-Mev neutrons from the $T(d,n)He^4$ reaction, produced by 1.5-Mev deuterons. The cross section relative to that at $E_n=14.2$ Mev, where the value is known to be 26±4 mb,[2] is at 12.5 Mev, 1.18; 13 Mev, 1.12; 15 Mev, 0.90; 16 Mev, 0.77; 17 Mev, 0.67; 17.9 Mev, 0.65; and 18.3 Mev, 0.64. The neutron energy spread varied from 0.2 to 0.4 Mev, and the ratios given are reliable to 10%. A detailed explanation of the peak shape will be given.

* On leave of absence from the University of Kentucky.
[1] Good, Kunz, Muckenthaler, Neiler, and Schenck, ORNL-1798, p. 32; R. B. Murray, ORNL-2081, p. 191, and private communication.
[2] F. L. Ribe, Phys. Rev. 103, 741 (1956).

K3. Lifetime of the 478-kev State of Li^7.* C. P. SWANN, F. R. METZGER, AND V. K. RASMUSSEN, *Bartol Research Foundation.*—A copious source of Doppler-broadened 478-kev γ rays was provided by bombarding a thick lithium target with 1.85-Mev protons. Using this source nuclear resonance fluorescence in Li^7 was observed in both a scattering and a self-absorption experiment. In both measurements nonresonant effects were eliminated by comparing LiF with graphite. The scatterers were matched principally for the effect of the 17-Mev capture radiation, whereas the absorbers were matched for electronic absorption. From the kinematics of the $Li^7(p,p')Li^{7*}$ reaction, it may be seen that gamma rays of the proper energy to give resonance fluorescence will be confined to a conical zone of half-angle 60° about 89° to the beam. The distribution of resonant gamma rays within this zone has been measured by resonance scattering and indicates that the inelastic protons are predominantly in the forward and/or backward direction. Assuming no slowing down of the Li^{7*} recoils it is found that the lifetimes determined from the scattering and absorption experiments agree well within the errors. The preliminary value for this mean life is $(9\pm2)\times10^{-14}$ sec.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

K4. Search for Higher Excited States of Li^5 and Li^6 by Means of the $Li^7(d,p)Li^8$ and $Li^7(d,t)Li^6$ Reactions.* E. W. HAMBURGER AND A. I. HAMBURGER, *University of Pittsburgh.*—Earlier work on these reactions at this laboratory[1] has been repeated and extended using cleaner natural lithium targets. The proton and triton spectra were observed at $\theta_{lab}=14°$ and 25° (protons also at 10°) in the energy ranges corresponding to excitations of Li^8 between 2.28 and 8 Mev and of Li^6 between 4.4 and 8.5 Mev. All spectra exhibit a background probably due to many-particle breakup. No Li^8 levels were observed; any narrow ($\Gamma<80$ kev) level having $\sigma>1$ mb/sterad would have been observed. Only one triton group was observed, corresponding to the broad 5.4-Mev level in Li^6; any narrow ($\Gamma<80$ kev) level with $\sigma>0.3$ mb/sterad would have been observed.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Levine, Bender, and McGruer, Phys. Rev. 97, 1249 (1955).

K5. Neutron Yields from Light Element (α,n) Reactions.* R. L. MACKLIN AND J. H. GIBBONS, *Oak Ridge National Laboratory.*—By use of the doubly charged α-particle beam from the ORNL 5.5 Mv Van de Graaff, total, absolute neutron yields[1] have been measured for the following reactions where the alpha-energy range (Mev) covered is indicated by parentheses: $Li^7(\alpha,n)B^{10}$, B^{10*}(4.4–8.2), $Be^9(\alpha,n)C^{12}$, C^{12*} (2.5–8.2), and $B^{10}(\alpha,n)N^{13}$, N^{13*}(2.5–4.8). Major resonance energies observed for the compound nuclei formed are B^{11}: 5.15 (11.95), 7.15 (13.22); C^{13}: 2.58 (12.44), 4.00 (13.43), 4.50 (13.78), 5.75 (14.64), 7.8 (16.06); N^{14}: 2.99 (13.75), 4.7 (14.97), where the first number given is α energy (Mev) and the number in parentheses is the corresponding excitation energy (Mev). The reaction $B^{10}(n,\alpha)Li^7$ has been computed by reciprocity for energies up to $E_n=5.64$ Mev, the threshold for $Li^7(\alpha,n)B^{10*}$. The cross-section extrapolation to zero neutron energy is in good agreement with directly measured values. The cross section for $Li^7(\alpha,n)B^{10*}$ has been computed by using literature values for the cross section of $B^{10}(n,\alpha)Li^7$ and the reciprocity relation.

* Work supported by the U. S. Atomic Energy Commission.
[1] R. L. Macklin, Nuclear Instr. 1, 335 (1957).

K6. Angular Distributions of Protons from $Be^9(d,p)Be^{10}$ at Low Angles.* J. R. CAMERON, *University of Pittsburgh.*—Angular distributions and absolute cross sections were obtained for the 0-, 3.37-, 5.97-, 6.26-, and 7.37-Mev levels of Be^{10} with $E_d=14.9$ Mev. Data were taken down to 0° by removing the Faraday cup and monitoring the beam with the elastically scattered deuterons. The 6.18, 7.54, and 9.27 levels were also observed but angular distributions were not obtained. The angular distributions of the ground state and 3.37-Mev levels are best fitted by $l=1$ stripping curves but for angles less than 10° the experimental points are considerably below the theoretical curves. For the 5.96- and 6.26-Mev levels the best fit is obtained with $l=0$ but $l=1$ assignments are not excluded. The 7.37-Mev level is best fitted with $l=2$.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

K7. $B^{10}(n,t)$ and $Be^9(n,t)$ Cross Sections. M. E. WYMAN, *Los Alamos Scientific Laboratory.*—Absolute beta-counting techniques were used to measure the tritium yield from neutron irradiated samples of boron-10 and beryllium-9. Using various monoenergetic neutrons from the Los Alamos Accelerators, the results given in Table I were obtained.

TABLE I.

Material	Neutron energy (Mev)	n,t cross section in millibarns
Be^9	14.1	17.8± 1.3
B^{10}	4.0	95 ±10
B^{10}	5.6	242 ±12
B^{10}	9.6	123 ±15
B^{10}	14.1	85 ± 6

These results agree with measurements made with emulsion techniques.[1]

* This work was done under auspices of the U. S. Atomic Energy Commission.
[1] G. M. Frye and J. H. Gammel, Phys. Rev. 103, 328 (1956).

K8. Angular Distributions of Protons from $B^{10}(d,p)B^{11}$.* O. M. BILANIUK AND J. C. HENSEL, *University of Michigan.*—A study of the proton groups from the reaction $B^{10}(d,p)B^{11}$ leading to levels in B^{11} at 8.92, 9.19, and 9.28 Mev has been made with 7.8-Mev deuterons from the University of Michigan cyclotron. Using the medium resolution magnetic analyzer[1] and thin targets prepared by evaporation of enriched B^{10} onto gold leaf, a resolution of 20 kev was obtained. The measured angular distributions of protons are fit by Butler curves using $r_0=6.0\times10^{-13}$ cm and the following values of l_n: $l_n=2$ with a small admixture of $l_n=0$ for $B_{8.92}{}^{11}$, $l_n=0$ for $B_{9.19}{}^{11}$, and $l_n=0$ for $B_{9.28}{}^{11}$. Since the ground state of B^{10} is $J=3+$, the character of each of the final states, $B_{8.92}{}^{11}$, $B_{9.19}{}^{11}$, and $B_{9.28}{}^{11}$ is restricted to $J=\frac{1}{2}+$, $\frac{3}{2}+$. The high relative intensity of these proton groups at the stripping peak compared to other groups from B^{11} in addition to the good fit by the Butler curves suggests that all three are single particle states. Interpretation of these results in terms of possible nuclear configurations will be given.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] Bach, Childs, Hockney, Hough, and Parkinson, Rev. Sci. Instr. 27, 516 (1956).

K9. Angular Distributions in the $B^{11}(\alpha,p)C^{14}$ Reaction.* L. L. LEE, JR., AND J. P. SCHIFFER, *Argonne National Laboratory.*—Angular distributions and excitation curves for the ground-state protons from the $B^{11}(\alpha,p)C^{14}$ reaction have been measured for α-particle energies between 2 and 4 Mev. Analysis of the angular distributions at the 2.07-Mev resonance leads to an assignment of $J=\frac{5}{2}+$ in agreement with neutron scattering[1] from N^{14}. The resonance reported at 2.60 Mev from a study[2] of the $B^{11}(\alpha,n)N^{14}$ reaction has been resolved into two resonances of nearly the same resonant energy and widths of about 60 kev. Reported resonances at 2.93 and 2.97 Mev have been observed with much smaller cross sections in this reaction than in the (α,n) reaction. Approximately 150 angular distributions have been measured over the energy region studied. These were taken at 4-kev intervals over the regions where the cross section was changing rapidly with energy, and at larger intervals between resonances. A least squares fit to the angular distributions was made in terms of Legendre polynomials by use of a high-speed computer. Spin and parity assignments based on this analysis will be discussed.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. L. Fowler and C. H. Johnson, Phys. Rev. 98, 728 (1955).
[2] Bonner, Kraus, Marion, and Schiffer, Phys. Rev. 102, 1348 (1956).

K10. Resonant Absorption of Gamma Rays in B^{11}.* LUISE MEYER-SCHÜTZMEISTER AND S. S. HANNA, *Argonne National Laboratory.*—The method used previously[1] to observe the resonant absorption of gamma rays has been applied to the 9.19-Mev level in B^{11}. In the radiative capture of particles of fixed energy and direction of motion, the energy of the radiation varies with angle but is definite at a given angle. The 9.16-Mev radiation from $C^{13}(p,\gamma)N^{14}(E_p=1.76$ Mev) was observed through a slit having an angular width of about one degree. Absorption into the 9.19-Mev level in B^{11} was obtained by interposing a boron sample between the source and the slit and finding the resonant energy by varying the angle of observation. At an angle of 30° an 8% absorption was measured for a 70-cm thickness of boron. From the half-width of the adsorption dip we estimate a total width of less than 100 ev for the level in B^{11}. The strength of the absorption indicates a partial width $(2I+1)\Gamma_\gamma\simeq0.8$ ev for the 9.19-Mev radiation. The inverse reaction $Li^7(\alpha,\gamma)B^{11}$ is weak and only recently has been observed in this laboratory.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. S. Hanna and L. Meyer-Schützmeister, Phys. Rev. 103, 1644 (1957).

K11. Proton Angular Distributions and $p-\gamma$ Correlations in the Scattering of 10.8-Mev Protons by C^{12}.* T. H. BRAID AND J. L. YNTEMA, *Argonne National Laboratory.*—The 10.8-Mev proton beam from the Argonne 60-inch cyclotron is being used to investigate the inelastic scattering from C^{12}. The measurements are made in the 60-inch scattering chamber.[1] The elastically scattered protons and those scattered from the 4.43-Mev first excited state have been observed at angles from 10° to 160° to the beam direction at 10° intervals. In each case the differential cross section shows distinct differences from those measured by others at slightly lower energies. For protons scattered at $\theta_p=30°$, an angular correlation with the 4.43-Mev γ rays from the first excited state has been measured in the range $\theta_\gamma=30°$ to 120°. This correlation shows a minimum at $\theta_\gamma=72°$ approximately. The tentative conclusion is that at least part of the inelastic scattering cross section at this energy is due to a direct interaction process. More complete angular correlation measurements are being made for various values of θ_p and the results will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. L. Yntema, Bull. Am. Phys. Soc. Ser. II, 2, 349 (1957).

K12. Upper Limit for the Ground-State De-Excitation of C^{13*} (7.65 Mev).* S. F. ECCLES AND D. BODANSKY, *University of Washington.*—This level was excited by inelastic scattering of 42-Mev alpha particles. De-excitation to the ground state, by gamma rays or electron pairs, can be recognized by observing coincidences between the inelastically scattered alpha particles and recoiling nuclei. The alpha particles were identified in a phoswich scintillation counter, and the recoil nuclei in a proportional counter which distinguishes them from lighter particles. The over-all performance of the system, including efficiency and accidental rates, was determined by observing similar coincidences for elastic scattering and for inelastic scattering from the 4.43-Mev level. Extrapolation of these results indicates that the proportional counter will detect at least 20% of the recoil nuclei accompanying observed alpha particles from the 7.65-Mev level. For 50 000 such alpha particles, 7 coincidences were observed at the expected angle and for 55 000 alpha particles, 5 accidental coincidences were observed at neighboring angles. It is concluded that there is less than one chance in ten that de-excitation to the ground state has a probability exceeding 0.1%. Studies are currently being undertaken on the details of the alternative process, dissociation into alpha particles.

* Supported in part by the U. S. Atomic Energy Commission.

K13. Measurement of the $C^{13}(n,p)B^{13}$ Cross Section. W. E. KREGER AND B. D. KERN,* *U. S. Naval Radiological Defense Laboratory.*—The cross section for the $C^{13}(n,p)B^{13}$ reaction has been obtained at 16.3 Mev in a measurement which is a considerable improvement over an earlier one.[1] A pulsed 0.75-Mev deuetron beam impinged on a tritium target to produce a nearly monoenergetic pulsed neutron source. The neutron flux density was established by the use of a Li^6I scintillation counter with the $Li^6(n,t)He^4$ cross section taken as 26 mb at 14.2-Mev neutron energy. The C^{13} nuclei were contained in a 5-inch diameter by 3-inch high plastic scintillator which was attached to a DuMont 6364 photomultiplier tube. The 18-msec B^{13} beta activity in the scintillator was observed with a time analyzer system in nine 7-msec intervals during the 130-msec period between beam pulses. The high end-point energy of the beta spectrum, 13.4 Mev, made it possible to discriminate against low-energy background and still count with good statistics. The cross section obtained was 28+7 mb, with the principal uncertainty being in the shape of the beta-ray spectrum. Further investigation of the

spectrum and of the cross section as a function of neutron energy is planned.

* On leave of absence from the University of Kentucky.
[1] Kreger, Bolotin, and Edelsack, USNRDL-TR-81 (1956).

K14. Angular Distribution of Inelastically Scattered Protons from Various Elements at 40 Mev.* SHEAU-WU CHEN, *University of Minnesota.*—Angular distributions of inelastically scattered protons from the first three excited states of C^{12}, the first excited state of Li^6, and the second excited state of Li^7 have been obtained at a proton energy of 40 Mev. All angular distributions are measured from 20° to 150° except the first excited state of C^{12} for which measurements go to 5°. The proton beam from the second section of Minnesota Linear Accelerator was used in this experiment. A NaI crystal, coupled with a Lucite light pipe to a photomultiplier was used as the detector and a 20-channel pulse analyzer was used to take the spectra. In the lithium experiments, enriched isotopes were used for the targets. The thickness of the targets was determined indirectly by comparing the elastic groups with that from a natural lithium target. The target holder was designed so that targets could be moved from the dry box to the scattering chamber in an evacuated system. The data will be discussed in terms of current direct interaction theories.[1,2]

* Supported in part by the U. S. Atomic Energy Commission.
[1] Austern, Butler, and McManus, Phys. Rev. 92, 350 (1953).
[2] Levinson and Banerjee, Ann. Phys. 2, 471 (1957).

FRIDAY MORNING AT 9:30

Shoreham, Main Ballroom

(O. OLDENBERG presiding)

Invited Papers

KA1. Scintillations of Radio Stars. G. A. HARROWER, *Queen's University, Kingston, Ontario.* (30 min.)

KA2. Properties of the Upper Atmosphere from Minitrack Observations on Sputnik I. R. JASTROW, *U. S. Naval Research Laboratory.* (30 min.)

KA3. Artificial Modification of the Upper Atmosphere. MURRAY ZELIKOFF, *Cambridge Air Force Research Center.* (30 min.)

KA4. Laboratory Investigations Related to Upper-Atmosphere Research. OTTO OLDENBERG, *Air Force Cambridge Research Center and Harvard University.* (30 min.)

FRIDAY MORNING AT 9:15

Sheraton-Park, Burgundy Room

(J. L. FOWLER presiding)

Neutron Physics III

L1. Use of a Hydrogen Bubble Chamber as a Fast-Neutron Spectrometer.* HAROLD E. ADELSON, HOYT A. BOSTICK, BURTON J. MOYER, AND CHARLES N. WADDELL.† *University of California, Berkeley.*—The Alvarez 4-in. hydrogen bubble chamber[1] has been utilized as a fast-neutron spectrometer. The neutron energy is determined by the range and angle of the recoil proton. Stereo photographs of the tracks are read with an electronic coordinate-measuring device. The neutron energy is calculated by an IBM 650 computer. The resolution of the system was determined by using almost monoenergetic 14.1-Mev neutrons from the *d-t* reaction. Using neutron collimation and accepting recoil tracks up to 30°, the measured peak had a full width at half-maximum of 1.3 Mev. The efficiency of the spectrometer was computed by considering the variation of the *n-p* cross section, the angular acceptance limits, and the change in active length of the chamber with proton energy. The efficiency for 10-Mev neutrons is 4.8%. Examination of the angular distribution and spectra of recoil protons indicates that the spectrometer is useful for neutrons above 5 Mev.

* Work supported by the U. S. Atomic Energy Commission.
† Now at the University of Southern California.
[1] D. Paramentier, Jr., and A. J. Schwemin, Rev. Sci. Instr. 26, 954 (1955).

L2. Neutron Spectrum, Angular Dependence, and Yield from 31.5-Mev Proton Bombardment of Selected Targets.* HOYT A. BOSTICK, HAROLD E. ADELSON, BURTON J. MOYER, AND CHARLES N. WADDELL.† *University of California, Berkeley.*—Protons from the University of California 31.5-Mev linear accelerator were used to bombard thin targets of beryllium, melamine (nitrogen), aluminum, cobalt, nickel-58, and nickel-60. Neutrons arising from the resulting reactions were detected in the UCRL 4-in. liquid hydrogen bubble chamber as described in the preceding abstract. Three spectrometer positions, 53°, 90°, and 127° in the laboratory system, were employed to measure the angular dependence of neutron production from these targets. The nickel and cobalt samples were chosen for study in an effort to investigate the reported low neutron yield of thick natural nickel targets bombarded by 31.5-Mev protons.[1] Preliminary analysis indicates that nickel-58 has less than one-half the average neutron yield of nickel-60 and cobalt in the range of 5 to 25 Mev. More precise results for all targets will be presented and the angular dependence will be discussed.

* Work supported by the U. S. Atomic Energy Commission.
† Now at the University of Southern California.
[1] Tai, Millburn, Kaplan, and Moyer, Phys. Rev. (to be published).

L3. Cross Section Measurements with Bevatron Neutrons.* JOHN H. ATKINSON, WILMOT N. HESS, VICTOR PEREZ-MENDEZ, AND ROGER W. WALLACE, *University of California, Berkeley.*—A counter telescope is being used to measure

attenuation cross sections for Bevatron neutrons in good and poor geometry. The telescope consists of three scintillation counters and a gas Čerenkov counter. The neutrons are detected by the charged pions produced in a beryllium or aluminum converter. The threshold energy of the detected pions, and hence of the incident neutrons, is determined by the gas pressure in the Čerenkov counter. Electrons from π^0 mesons produced in the converter are eliminated by a lead filter and a sweeping magnet. Using a neutron threshold of about 3 Bev, we have measured the cross section of Pb as a function of the geometry. From good-geometry measurements ($\theta/2=0.184$ deg), we have obtained $\sigma_t=2.32\pm0.09$ barns and from poor-geometry measurements ($\theta/2=4.09$ deg), $\sigma_a=1.62\pm0.12$ barns. These are preliminary results. Similar measurements are in progress on other elements.

* Work done under the auspices of the U. S. Atomic Energy Commission.

L4. Calculation of the Average Neutron Capture Cross Section. L. C. THOMPSON AND C. F. COOK, *Convair, General Dynamics Corporation.*—The average neutron capture cross section has been calculated as a function of energy from thermal to 0.3 Mev for nuclei with relatively dense level spacing in the measured total neutron cross section. The method of calculation is based on a paper by Feshbach, Peaslee, and Weisskopf[1] in which the neutron capture cross section is averaged over a number of energy levels. A knowledge of the average neutron resonance width at 1 ev, the average radiation resonance width, and the average distance between energy levels in the compound nucleus is required for the calculation. The accuracy of the method is found to be about a factor of 2 when the calculated results are compared to existing measurements.

[1] Feshbach, Peaslee, and Weisskopf, Phys. Rev. 71, 145 (1947).

L5. Measurement of the Flux of Fast Neutrons with Nuclear Emulsions.* J. H. ROBERTS, *Northwestern University.*—New Ilford fine grain L2 emulsions make it possible to use proton recoil tracks to measure the neutron flux of anisotropic[1] neutron sources down to ~0.2 Mev. In some cases it is possible to extend this to lower energies (~0.05 Mev) with Li^6 speck loaded plates.[2] The method is tested with exposures to monoergic neutron groups from $Li^7(p,n)$, and the relative intensities compared with long counter data. The method is illustrated by the measurement of the spectrum inside a fast critical assembly. Data reduction is carried out with an IBM 650.

* Work supported by the U. S. Atomic Energy Commission through Argonne National Laboratory subcontract.
[1] J. H. Roberts, Rev. Sci. Instr. 28, 677 (1957).
[2] J. H. Roberts and F. E. Kinney, Rev. Sci. Instr. 28, 610 (1957).

L6. Pulse-Height Distributions Produced by Neutrons in a NaI Crystal.* S. M. SHAFROTH, E. N. STRAIT, AND R. T. CARPENTER, *Northwestern University.*—Pulse-height distributions in a 1¾-in. diam×2-in. NaI cylinder produced by neutrons from the $Li^7(p,n)Be^7$ reaction have been observed simultaneously with counts in a shielded long counter for the following neutron energies: 0.7 and 75, 166, 341, 469, 705 and 193, 994 and 520, 1162 and 698 kev. The long counter was calibrated at the highest proton energy (2.94 Mev) by comparison with proton knock-on tracks in Ilford C2 emulsions. From the curves which will be presented one can estimate the number of neutron produced pulses in the 3–7 Mev gamma pulse-height region in any experiment if he knows the neutron flux and energy distribution incident on the crystal. The pulse-height distribution is approximately linear over much of the region between 3 and 7 Mev. The intercept of this line with the gamma equivalent energy axis is at about 6.6 Mev, the binding energy of a neutron in I^{128}, plus the neutron kinetic energy when the neutrons are monoergic.

* Supported in part by the National Science Foundation.

L7. Approximation for Solution of the Neutron Transport Equation.* P. B. DAITCH, *Combustion Engineering, Inc.*—A method of solution of the monoenergetic transport equation in one spatial dimension has been developed. The essential feature is the utilization of an expansion in Legendre functions of the space dependence of the directional flux. Approximate solutions are obtained by truncating the Legendre function expansion. The angular coefficients are given as the solution of a set of coupled integral equations whose solution for arbitrary boundary conditions is reduced to linear algebraic equations and simple quadratures. Transport boundary conditions are fulfilled at all boundaries and interfaces. The method has particular merit in that, even in low-order approximations, it can yield reliable results in cases of highly absorbing media and black boundary conditions. Also, the general solution is obtained with the source expanded in Legendre functions which simplifies solution with curved source distributions and in multigroup theory. In general, the smaller the optical thickness, the fewer terms need be carried in the series to obtain a desired accuracy. Some analytic estimates of the accuracy have been obtained. Some numerical results will also be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

L8. Neutron Thermal Inelastic Scattering by Bound Atoms. A. W. MCREYNOLDS AND W. L. WHITTEMORE, *General Atomic,* AND ARNE ANDRESEN, *Jener, Kjeller, Norway.*—In the energy range below about 1 ev, the cross section $\sigma(\mathbf{k},\mathbf{k}',T)$ for change of a neutron's propagation vector from $\mathbf{k}$ to $\mathbf{k}'$ by inelastic scattering in a medium at temperature T, is no longer characteristic of free atoms but depends on interatomic binding forces. Using monoenergetic neutron beams, ranging from 0.05 to 0.3 ev, from crystal spectrometers at Brookhaven National Laboratory, this dependence has been studied by measurements of the total cross section, angular distribution, and average scattered energy, for H in various chemical bonding states and for C. H in H_2O behaves qualitatively as if free, with smooth variation of both total cross section and energy loss with incident energy. The tighter binding of H in $ZrH_{1.8}$ gives discrete states, at 0.13-ev energy intervals, characteristic of an isotropic harmonic oscillator. Energy loss per collision is negligible for neutrons of lower energy, but has maxima at the 0.13, 0.26, etc., levels. There are corresponding peaks in total cross section above these energy thresholds, in agreement with Fermi's theoretical curve. For graphite, the predominance of elastic diffraction scattering over inelastic necessitates higher resolution techniques. These show the product of cross section and logarithmic energy loss per collision ($\xi\sigma$) lower by about a factor of 3 than the value for free carbon.

L9. Study of Neutron Thermal Inelastic Scattering Using Time-of-Flight Technique. W. L. WHITTEMORE* AND A. W. MCREYNOLDS, *General Atomic* AND I. PELAH,* *Weizmann Institute and Israel Atomic Energy Commission.*—As part of our investigation of the cross section $\sigma(E_0,E,\theta)$ for neutron scattering from energy E_0 to energy E through angle θ, we have studied, using neutron time-of-flight techniques, several materials including zirconium hydride, liquid and solid water, hydrogen in various chemical bonding states, and graphite. Our measurements have been made with a scattering angle of about 90 degrees and divide naturally into two types in which the significant difference is the energy E_0 of the incident neutron. For one set of measurements, we have used a beam of very slow neutrons to study the vibrational spectra of several materials. For the case of zirconium hydride we will discuss the effects on the discrete hydrogen levels (at 0.13 ev, 0.26 ev, etc.) due to changes in concentration of hydrogen and due to the addition to the lattice of heavy impurity atoms.

The other type of measurement was made with a somewhat higher energy E_0(0.1–0.2 ev). In this case, the energy spectrum of the scattered beam shows directly the transfer of energy to the array of scattering atoms. The results from this type of measurement are intimately related to those already discussed. Results will be presented for a variety of hydrogenous materials including in particular liquid and solid water.

* Guest Scientist, Brookhaven National Laboratory, Upton, New York.

FRIDAY MORNING AT 9:15

NBS, East Building

(C. ZENER presiding)

Metals

LA1. Electron Energy Losses and Electromagnetic Transitions in Aluminum.* H. MENDLOWITZ, *National Bureau of Standards.*—When electromagnetic radiation passes through matter, the exchange of energy between the electromagnetic field and the material medium is proportional to $\omega \operatorname{Im}\epsilon(\omega)$, where ω is the frequency of the radiation and $\operatorname{Im}\epsilon(\omega)$ is imaginary part of the complex dielectric constant of the medium. When electrons traverse a material medium the rate of energy exchange is proportional to

$$\omega \operatorname{Im}\epsilon(\omega)/|\epsilon(\omega)|^2, \qquad (1)$$

where ω is the frequency of the Fourier component of the field.[1] In a number of materials such as aluminum, the characteristic energy losses have been attributed to the vanishing of the denominator in Eq. (1). However, it will be shown that even in aluminum it has not been shown conclusively that the characteristic electron energy losses do not arise from the peaking of the numerator in Eq. (1).

* Supported in part by the U. S. Atomic Energy Commission.
[1] Marton, Leder, and Mendlowitz, *Advances in Electronics and Electron Physics* (Academic Press, Inc., New York, 1955), Vol. VII, p. 183.

LA2. Electron Characteristic Energy Losses in Indium and InSb. BERNARD GAUTHE,* *National Bureau of Standards* (introduced by L. Marton).—We have measured the energy loss spectra of electrons in indium and in one of its intermetallic compounds, InSb. Preliminary results for indium indicate a main loss line at 21.2 ev, with another weak one at 5.8 ev. Thin films of InSb were prepared by a fast vacuum evaporation from the powdered compound. There are indications of only one loss line at 12.5 ev in InSb. This spectrum is significantly different from both the pure indium and antimony spectra, so we believe that we have successfully obtained the InSb compound in thin films. The energy loss in antimony has also been reinvestigated in order to make this comparison, and was found to be in good agreement with previous results.[1] In contrast with the results for aluminum, the indium energy loss does not seem in accordance with the plasma theory, if we assume three "free" electrons per atom.

* On leave of absence from University of Paris, Laboratoire de Chimie-Physique.
[1] L. B. Leder, Phys. Rev. **103**, 1721 (1956).

LA3. Surface Oscillations of the Electron Plasma in a Metal.* EDWARD A. STERN AND RICHARD A. FERRELL, *University of Maryland.*—In addition to bulk plasma oscillations in a degenerate electron gas of infinite extent, other modes of oscillation can exist at the surface of a bounded gas.[1] These new surface oscillations may possibly have some characteristics different from those of the bulk oscillations, such as coupling with electromagnetic radiation. This question was investigated by a simple dielectric theory differing somewhat from Ritchie's.[1] The electron gas was considered a slab bounded by parallel infinite planes. When the plasma wavelength is small compared to that of light at the same frequency and no coupling with the electromagnetic field is possible, it is found that two different types of surface oscillations can exist. As established by Ritchie,[1] these have frequencies given by $\omega_p 2^{-\frac{1}{2}}(1\pm e^{-kt})^{\frac{1}{2}}$, where ω_p is the bulk plasma frequency, k the wave number, and t the thickness. At longer wavelengths, on the other hand, coupling with light may become a possibility. Retardation effects then become important, however, and are presently under investigation.

* Investigation supported by the U. S. Signal Corps and by the Office of Naval Research.
[1] R. H. Ritchie, Phys. Rev. **106**, 874 (1957).

LA4. Characteristic Energy Loss of Electrons Passing through Metal Foils: Continuum of One-Electron Excitations of a Degenerate Electron Gas.* ARNOLD J. GLICK AND RICHARD A. FERRELL, *University of Maryland.*—Hubbard[1] has expressed the inelastic electron scattering intensity in terms of Lindhard's frequency and wave-number dependent dielectric constant, K, of the medium through which the electron passes. Hubbard's formula depends upon both the real and imaginary parts of K, thereby incorporating both the individual-electron and collective aspects of the phenomenon. The absorption of energy by one-electron transitions is represented by $\operatorname{Im}K$, while the collective response of the electron gas in screening out the incident electron is taken into account by $\operatorname{Re}K$. This dielectric theory, which successfully describes the details of plasmon production,[1] has now also been used for detailed numerical calculations of the continuum of one-electron energy losses as a function both of energy and angle. Because of the sum rule,[1] the intensity of the continuum becomes appreciable only as the plasmon cutoff is approached. With suitable experimental precautions it should be susceptible of detection.

* Investigation supported by the Office of Naval Research.
[1] For references see R. A. Ferrell and J. J. Quinn, Phys. Rev. **108**, 570 (1957).

LA5. Role of Band-Band Transitions in Characteristic Energy Losses of Electrons Passing through Metal Films.* W. H. LUPTON, R. A. FERRELL, AND R. D. MYERS, *University of Maryland.*—Various investigators of the characteristic energy losses in aluminum have found a small peak at approximately 7 ev in addition to the predominant peak at 15 ev due to plasmon production, and have speculated whether it is due to band-band transitions. According to Hubbard[1] the energy loss probability is proportional to $|\operatorname{Im}K^{-1}|$, where K is the complex dielectric constant, and hence $\operatorname{Im}K$ would have a peak at 7 ev. But if $\operatorname{Re}K \cong 1-\omega_p^2/\omega^2$ and $|\operatorname{Im}K^{-1}|$ has its maximum possible value, the calculated 7-ev energy loss probability is still only 0.7% of the probability of plasmon production. Furthermore, optical data do not exhibit such a peak at 7 ev. Hence we conclude that band-band transitions are not responsible for the 7-ev peak, which can instead be

possibly ascribed to carbon contamination on the target foils. Calculations of the indirect effect of band-band excitation on the plasmon dispersion relation are in progress.

* Investigation supported by U. S. Air Force Office of Research and Development and by the Office of Naval Research.
[1] J. Hubbard, Proc. Phys. Soc. (London) **A68**, 976 (1955).

LA6. Electron Energy Bands in Sodium.* JOSEPH CALLAWAY, *University of Miami.*—A plane wave method has been applied to a calculation of energy bands in sodium. The potential energy of a valence electron is expressed in atomic units as $-2/r+Ae^{-\mu r}$ where the constants A and μ are evaluated from spectroscopic data. It is required that the logarithmic derivative of the valence electron wave function at some large r calculated for an eigenvalue of the free atom in the potential given above equal the value given by the quantum defect method. Values of 24.578 and 2.101 were found for A and μ respectively, using the lowest s and p states. The presence of the repulsive term in the potential makes it unnecessary to orthogonalize the valence electron wave function to the core states. The energy of the lowest state of the valence electron in the solid was found to be -0.597 ry, determined from a fourth-order secular equation. Results for other states will be presented and compared with those obtained by the quantum defect method.

* Supported by the Air Force Office of Scientific Research.

LA7. $M_{2,3}$ Emission Spectrum of Manganese.* D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University.*—The manganese $M_{2,3}$ emission band was investigated in connection with a sequential study of the valence band spectra of the elemental solids belonging to the iron group. As in the case of the corresponding copper spectrum reported previously,[1] the valence band is superimposed on a continuum emitted by the target. The intensity of the continuum does not vary smoothly because of the presence of short wavelength radiations diffracted in higher orders and also because of the modification by absorption which takes place in the surface of the grating. A correction for the background was carried out utilizing an exposure obtained with a neighboring element (Ni). A preliminary examination of the $I(E)/\nu^3$ distribution indicates that the band has a peak at 45.8 ev (270 A) and excluding satellite structure has an over-all width of 16 ev. In isolating the relatively weak characteristic band from the strong background, it is observed that small fluctuations in the microphotometer traces are emphasized in the intensity variation over the long wavelength region. Such structures are further magnified when one includes the frequency effect in deducing the $I(E)/\nu^3$ plot.

* Supported in part by the Office of Ordnance Research, U. S. Army.
[1] D. H. Tomboulian and D. E. Bedo, Bull. Am. Phys. Soc. Ser. II, **2**, 339 (1957).

LA8. Measurement of Lattice Vibrations in Vanadium by Neutron Scattering.* D. J. HUGHES, C. M. EISENHAUER,† I. PELAH,‡ AND H. PALEVSKY, *Brookhaven National Laboratory.*—The energy spectrum of slow neutrons inelastically scattered by vanadium metal has been measured by the time-of-flight technique. The incident neutrons, of energy 0.0035 ev, are produced by a beryllium filter. The neutrons gain energy in scattering by absorbing quanta of lattice vibration energy (phonons). As the nuclear scattering amplitude of vanadium is incoherent, the energy distribution of scattered neutrons is directly related to the frequency distribution of the lattice vibrations.[1] The measured neutron energy spectrum, as well as the derived frequency distribution, shows a clearly resolved double peak. This structure, which is distinctly different from the simple Debye distribution, but expected on the basis of detailed calculations, has heretofore not been amenable to direct measurement. The measured frequency distribution is compared with calculations for a body-centered cubic lattice by the Born-von Karman theory and qualitative agreement is obtained. A more exact comparison awaits measurement of the elastic constants of vanadium.

* Under the auspices of the U. S. Atomic Energy Commission.
† Now at National Bureau of Standards.
‡ On leave from Weizmann Institute and the Atomic Energy Commission of Israel.
[1] G. Placzek and L. Van Hove, Phys. Rev. **93**, 1207 (1954).

LA9. Normal Modes of Germanium by Neutron Spectrometry. B. N. BROCKHOUSE AND P. K. IYENGAR,* *Chalk River Laboratories.*—Complete dispersion curves of the normal vibrations of germanium in the symmetric [100] and [111] directions (and some results for other directions) have been obtained from scattered neutron energy distributions.[1,2] Some frequencies (units 10^{12} sec^{-1}) are as follows: restrahlen ($q=0$) 9.1; transverse optical at the zone boundary in the [100] direction (TO[100]) 8.3$_5$; TO[111] 8.4$_3$; longitudinal optical [111] 7.4±0.5; longitudinal acoustic [111] 6.6; LA[100] $=LO$[100] 6.9; TA[100] 2.50; TA[111] 1.95; errors TA ±0.15, others ±0.3. Identifications of the character of the phonons were made from the intensities and positions of the neutron groups in the reciprocal lattice. At low q the results for the acoustic branches agree with the known elastic constants. The results cannot be fitted by the Born-von Karman theory with general first and second neighbors forces. The low values for the TA modes probably account for the peculiar Θ_D vs T curve obtained from specific heat measurements. The far infrared spectra[3] can be almost completely interpreted as summation bands[4] in terms of our results.

* Visiting scientist from Atomic Energy Establishment, Bombay, India.
[1] B. N. Brockhouse and A. T. Stewart, Revs. Modern Phys. **30**, 236 (1958).
[2] B. N. Brockhouse and P. K. Iyengar, Phys. Rev. **108**, 894 (1957).
[3] R. J. Collins and H. Y. Fan, Phys. Rev. **93**, 674 (1954).
[4] M. Lax and E. Burstein, Phys. Rev. **97**, 39 (1955).

LA10. Structure of Copper Films.* BENJAMIN M. SIEGEL, *Cornell University.*—The structure of thin films of copper deposited by vacuum evaporation on mica substrates has been studied utilizing a technique in which transmission electron microscopy, surface replication, and electron diffraction observations can be made on the same film. Investigations have been made on films of thicknesses from 15 to 1000 A in which the deposits were made on freshly cleaved mica kept at temperatures ranging up to 450°C during deposition. When the copper is deposited on the mica at the higher temperatures there is crystallite growth which upon examination produces an interesting array of electron interference phenomena. The patterns obtained are interpreted in terms of defect structures such as stacking faults and dislocations.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command under contract No. AF18(600)-674.

LA11. Density Measurements of Thin Copper Films.* N. WAINFAN, M. HOMMEL, H. ZAPOLSKY, J. R. KENEMUTH, AND L. G. PARRATT, *Cornel University.*—A series of "smooth" copper films, evaporated onto optically flat Pyrex substrates, was investigated. Film thickness was determined from the multiple-beam x-ray interference patterns formed on reflection near the critical angle using equations based on an ideal three media model.[1] Mass per unit area was measured by a chemical colorometric method. In the range between 500 and 1100 A, films smooth enough to exhibit the x-ray interference pattern were found to have bulk density.[2] Present results for the above thickness range yield a density of 9.03±0.36 g/cc. The values compiled by Foote and Jette for bulk copper are between 8.914 and 8.953 g/cc.[3] Comparisons of x-ray thickness determinations with those obtained by optical interference methods will be discussed.

* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.
[1] H. Kiessig, Ann. Physik **10**, 769 (1931).
[2] M. S. Blois and L. M. Rieser, J. Appl. Phys. **25**, 338 (1954).
[3] F. Foote and E. R. Jette, Phys. Rev. **58**, 81 (1940).

LA12. Transmission Sputtering in Thin Metal Foils.* R. C. BRADLEY, *Cornell University.*—The discovery by Wehner[1] that sputtered particles are ejected preferentially along the directions of close packing of metal crystals suggests the possibility that during ion bombardment energy might be propagated a considerable distance into a crystal along these same close-packed directions, and might in fact lead to the ejection of atoms from the back side of thin metal foils. We have investigated this effect for 0.0002 in. foils of gold and aluminum under bombardment by inert gas ions of 800 ev energy. For the gold foils the results indicate that approximately one gold atom was ejected from the back face for every 10^3–10^4 ions incident on the front face, that 0.1% of these were positively charged, that their energy was low (<4 ev), and that the total yield was greatest for bombardment by Xe ions, less for A ions, still less for He ions, and undetected for bombardment by electrons of the same energy. For the aluminum foils, no transmission sputtering was detected and hence must have been less than 1 ejected Al atom for 10^5 incident ions.

* This research was supported by The U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] G. K. Wehner, Phys. Rev. 102, 699 (1956).

LA13. Mass Spectrometric Studies of Particles Sputtered from Tantalum and Platinum Surfaces.* ALBERT ARAKENGY AND RICHARD C. BRADLEY, *Cornell University.*—A mass spectrometric study of secondary ions sputtered from a Mo surface in high vacuum has previously been reported.[1] This work has now been extended to a study of Ta and Pt surfaces. The secondary ion yield as a function of surface temperature is quite different for the three metals: it increases with increasing temperature for Pt^+, decreases for Mo^+, and shows a marked hysteresis effect for Ta^+. For the Pt surface, (the only case where neutral sputtered particles were also studied) it is estimated that secondary ions comprise about 0.1% to 1% of the total yield of sputtered particles. Thermionic and secondary emission of positive ions of alkali metal impurities in the Pt have also been investigated and have led to a determination of the following activation energies: for desorption of Na from the surface, 1.9±0.1 ev; for bulk diffusion of Na, 4.7±0.1 ev; for bulk diffusion of *K*, 4.4±0.1 ev.

* This research was supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] Bradley, Stabler, and Arakengy, Bull. Am. Phys. Soc. Ser. II, 2, 269 (1957).

LA14. Properties of Hydrogen Adsorbed on Tungsten. J. EISINGER, *Bell Telephone Laboratories.*—The sticking probability of hydrogen on a single crystal tungsten ribbon [surface normal (113)] has been measured by means of a flash filament method.[1] The sticking probability was found to drop from an initial value of approximately 0.2 to a vanishingly small value for a surface covered with 8×10^{14} atoms per cm^2. The photoelectric work function of the same ribbon was measured as a function of the number of adsorbed atoms and was found to change from 4.54 ev for the atomically clean surface to approximately 5.0 ev for the covered surface. This corresponds to an effective dipole moment of 0.18 debye unit for an adsorbed hydrogen atom. Some evidence for the existence of two distinct adsorption states will be discussed. The present results will be compared with earlier experiments[2] in which hydrogen was adsorbed on evaporated tungsten and with results[3] for N_2 and CO adsorbed on the ribbon used in this experiment.

[1] J. A. Becker and C. D. Hartman, J. Phys. Chem. 57, 157 (1953).
[2] J. C. P. Mignolet, Rec. trav. chim. 24, 685 (1955).
[3] J. Eisinger, J. Chem. Phys. 27, 1206 (1957); 28, 165 (1958).

LA15. Theoretical Calculations of the Relaxation of Atoms Surrounding a Vacancy in Cubic Metals. L. A. GIRIFALCO AND V. WEIZER (sponsored by R. A. Lad).—The extent of relaxation of atoms surrounding a vacancy in several f.c.c. and b.c.c. crystals has been computed assuming a Morse-type pairwise potential acting between atoms in the crystal. The constants in the Morse function were obtained from empirical energy of cohesion, lattice parameter, and compressibility data by applying a lattice summation technique. Detailed calculations were made with the aid of electronic computer for Morse functions corresponding to the metals Fe, Ba, Na, Ca, Pb, Ni, and Cu. In all cases the relaxation effects were small, the nearest neighbor relaxation ranging from 3 to 5% for the b.c.c. crystals and from 0.1 to 0.7% for the f.c.c. crystals. The energy of vacancy formation has also been computed.

FRIDAY MORNING AT 9:30

Shoreham, West Ballroom

(R. K. WANGSNESS presiding)

Magnetism

M1. Generalized Overhauser Effect and its Application to Ferro- and Antiferromagnetism.* T. OGUCHI AND F. KEFFER, *University of Pittsburgh.*—The theory of the Overhauser effect may be formulated from general statistical-mechanical arguments,[1] indicating that a forced statistical redistribution may be made to occur in any subsystem whose principal contact with a heat bath is indirectly routed through some other statistically distributed system. In particular, we consider Overhauser nuclear polarization in ferro- and antiferromagnets. Here the main route of nuclear relaxation will generally be via the excitation and/or absorption of spin-wave quanta. At low temperatures multiple spin-wave processes should predominate over processes involving phonons. In order to conserve energy, at least one spin wave must be annihilated if a spin wave is created; this means that the nuclear relaxation rate depends strongly on the number of spin waves present. By resonance excitation of a large number, n_0, of $\mathbf{k}=0$ spin waves, with $n_0>\Sigma_{k\neq0}n_k$, (the number of thermally excited spin waves), we may force the nuclei to relax primarily to the $\mathbf{k}=0$ spectrum. We show that the resultant polarization is proportional to $\exp(-2\mu_n H-Sk\omega_0)/kT$, where ω_0 is the resonance frequency and S is the power saturation factor.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and supported by the Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] C. Kittel, Phys. Rev. 95, 589 (1954); J. Korringa, Phys. Rev. 94, 1388 (1954).

M2. High-Field Antiferromagnetic Resonance and Magnetic Properties of Single-Crystal Cr_2O_3.* SIMON FONER, *Lincoln Laboratory.*—Antiferromagnetic resonance was observed in Cr_2O_3[1] from 4.2°K to T_N with pulsed fields.[2]

Vibrating-sample-magnetometer[3] susceptibility measurements from 4.2°K to 350°K are also presented and applied to molecular field calculations of $(2H_EH_A)^{\frac{1}{2}}$ *versus* temperature. Below 77°K, $(2H_EH_A)^{\frac{1}{2}}$ equals 59±5, and line-widths are less than 900 gauss. H_A is much smaller than estimated earlier.[4] The resonance field is temperature dependent; maxima are 72 kilogauss at 250°K for 36 kmcps, and 48 kilogauss at 235°K for 70.7 kmcps. Dayhoff's results,[4] difficulties in extrapolating data near T_N, and effects of *anomalous* magnetic data, lattice distortions, and crystalline fields, are reviewed. Differences between Cr_2O_3 and MnF_2[5] are described. Calculations and experiments on angular dependence of resonance, multiple resonances, and frequency dependence are presented. Limitations of pulsed-field techniques for resonance measurements[6] are summarized.

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force under contract with M.I.T.
[1] Furnished by Dr. E. J. Scott, Jr., of the U. S. Naval Ordnance Laboratory and by Dr. W. H. Bauer of Rutgers University.
[2] S. Foner and H. H. Kolm, Rev. Sci. Instr. **28**, 799 (1957); **27**, 547 (1956).
[3] S. Foner, Rev. Sci. Instr. **27**, 548 (1956).
[4] McGuire, Scott, and Grannis, Phys. Rev. **102**, 1000 (1956); E. S. Dayhoff, Phys. Rev. **107**, 84 (1957).
[5] S. Foner, Phys. Rev. **107**, 683 (1956).
[6] S. Foner, Bull. Am. Phys. Soc. Ser. II, **3**, 42 (1957).

M3. Magnetostatic Modes in Ferrimagnetic Spheres. J. F. Dillon, Jr., *Bell Telephone Laboratories.*—Ferrimagnetic resonance experiments (9000 mc, 300°K) have been performed using single crystal spheres of yttrium iron garnet.[1] Rf magnetic fields of several different configurations were used to excite specific magnetostatic modes. A mounting technique was employed such as to eliminate dielectric inhomogeneities near the sample. Such inhomogeneities arise from the usual quartz or sapphire mounting rods. They have been observed to be responsible for the excitation of more complicated modes than would be expected from the unperturbed cavity fields. It has been found that supposedly spherical specimens produced by the usual tumbling procedures deviate slightly from true sphericity. In these experiments highly polished truly spherical samples were used. With these conditions there is no ambiguity about the identity of the mode representing the spacially uniform precession of the entire spin system. The spacings of the various modes do not vary with the crystal direction along which H_{dc} is applied. These results contrast with those of White and Solt on manganese ferrite[2] in several respects, *viz.*, the clear identity of the uniform precession and the constant mode spacing for the various crystal directions.

[1] Grown by J. W. Nielsen.
[2] R. L. White and I. N. Solt, Phys. Rev. **104**, 56–62 (1956). Solt, White, and Mercereau, J. Appl. Phys. **29**, 324 (1958).

M4. Detection of Ferromagnetic Resonance.* W. G. Egan and H. J. Juretschke, *Polytechnic Institute of Brooklyn.*—Ferromagnetic resonance in thin metal films, incorporated in the wall of a wave guide, has been detected by the appearance of a dc voltage across electrodes attached to the film and suitably oriented with respect to the steady magnetic field and the microwave fields. The signal is traced to the Hall effect interaction between the microwave components of the magnetization and of the wall currents and is explained quantitatively using the Hall effect properties of thin ferromagnetic films[1] and the theory of ferromagnetic resonance,[2] including eddy currents.[3] Because of the small interference of the microwave excitation with the dc signal in the detection circuit, the method allows observation of the resonance, and analysis of its properties, in the thinnest films.

* Supported in part by the Office of Naval Research.
[1] R. Coren and H. J. Juretschke, J. Appl. Phys. **28**, 806 (1957).
[2] N. Bloembergen, Phys. Rev. **78**, 572 (1950).
[3] C. Kittel, Phys. Rev. **73**, 155 (1948).

M5. Internal Consistency of the Heisenberg-Dirac Model for Antiferromagnetism.* J. Samuel Smart, *Brookhaven National Laboratory.*—Various high temperature approximations to the Heisenberg-Dirac model for antiferromagnetism may be used to predict the Néel temperature and physical properties above the Néel temperature. The results so obtained are in good qualitative agreement with experiment, but it has not been possible to make any very discriminating tests of the general consistency of the theory. This is principally because the theoretical treatments have usually been limited to spin ½ and nearest neighbor interactions, while practically all of the experimental data are on more complex systems. In an effort partially to bridge this gap, we have used the Bethe-Peierls-Weiss method[1] to calculate the susceptibility for spin values greater than ½. For systems which have *nn* interactions only, the theory makes predictions regarding T_N and $\chi(T_N)$ such that choice of a single energy parameter τ should be sufficient to obtain agreement between theory and experiment for both quantities. Thus, independent determinations of τ by the two methods provide a consistency check on the theory. Comparisons with experimental data will be presented, and the relative accuracy of the B-P-W, classical B-P-W, and molecular field theories will be discussed.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. A. Brown and J. M. Luttinger, Phys. Rev. **100**, 685 (1955).

M6. A Dynamic-Condenser Magnetic Fluxmeter.* S. B. Burson, D. W. Martin,† and L. C. Schmid, *Argonne National Laboratory.*—This instrument was designed to measure and control the flux density between the poles of an iron-core electromagnet. The sensing coil, rotating at 1800 rpm, generates approximately 0.115 v (rms) per gauss. A comparison signal, against which the emf of the coil is bucked, is generated electrostatically by a dynamic condenser. Its rotor plates are shaped to produce a sinusoidal wave form. The amplitude of the comparison signal is determined by a dc voltage applied between two stator sections which are juxtaposed on opposite sides of the rotor shaft. This voltage thus provides a measure of the field strength. An unbalanced condition results in the appearance of a 30-cy error signal at the stator sections (which are isolated with respect to ac). After amplification and synchronous rectification, this signal indicates the degree and phase of the imbalance. The motor speed is maintained constant by a precision 60-cy tuning fork. The stability of the fluxmeter is of the order of one part in 10 000, as determined by the reproducibility of the position of the 0.9759-Mev internal-conversion-electron line of Bi^{207}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at Georgia Institute of Technology.

M7. Neutron Diffraction Investigations of the Antiferromagnetic Ordering in MnI_2. J. W. Cable, M. K. Wilkinson, E. O. Wollan, and W. C. Koehler, *Oak Ridge National Laboratory.*—Neutron diffraction observations have been made on MnI_2 at temperatures down to 1.35°K to determine the existence of antiferromagnetic ordering in this compound at low temperatures. Since MnI_2 crystallizes in the hexagonal layer structure characteristic of CdI_2, it is isomorphous with $MnBr_2$ which becomes antiferromagnetic at 2.16°K,[1] but the interatomic distances in the iodide are about ten percent larger than those in the bromide. Antiferromagnetic reflections are observed from MnI_2 below 3.40°K, and the ordering transition to the antiferromagnetic state is extremely sharp. The magnetic structure could not be determined from powder diffraction patterns, and single crystal investigations were made with the specimen in an external magnetic field. These experiments show that the antiferromagnetic ordering consists of a structure domain pattern similar to that found in $MnBr_2$ but with a different arrangement of the atomic magnetic moments. When an external magnetic field is applied to the

sample, the entire crystal is transformed into a single antiferromagnetic domain, and this condition is only slightly altered when the magnetic field is removed.

[1] Wollan, Koehler, and Wilkinson, (Phys. Rev., to be published).

M8. Magnetization Studies and Possible Magnetic Structure of Barium Ferrate (III). WARREN E. HENRY, *U. S. Naval Research Laboratory.*—The pronounced temperature dependence[1] of the remanence of $BaO \cdot 6Fe_2O_3$ prompted an investigation of its field dependent magnetization at several temperatures, including the liquid helium range. The remanence becomes independent of temperature at low temperatures. At 295°K, the magnetization at 60 000 gauss is 1.13 Bohr magnetons per atom of iron in the barium ferrate (III) and in zero field, it is 0.55 Bohr magneton per atom. At 4.2°K, the corresponding values are 1.63 and 0.80, respectively. Previous work[2] on $\gamma - Fe_2O_3$ showed an average saturation magnetization of 1.25 Bohr magnetons per atom of iron, indicating a preference of magnetic ions for octahedral sites in the spinel structure. On the other hand, the hexagonal close-packed[3] barium ferrate (III) exhibited an average saturation magnetization near absolute zero of 1.67 Bohr magnetons per atom, indicating a random distribution of magnetic ions among the available 24 sites in the unit cell. These experimental results will be compared with theories of Néel, Gal'perin, and others.

[1] Fahlenbrach and W. Heister, Arch. Eisenhüttenw. **24**, 523 (1953).
[2] W. E. Henry and M. J. Boehm, Phys. Rev. **101**, 1253 (1956).
[3] Volrath Adelskold, Arkiv Kemi, Mineral. Geol. **12A**, No. 29 (1938).

M9. Single Crystal Anisotropy and Magnetostriction Constants of Several Ferromagnetic Alloys.* R. C. HALL, *Westinghouse Magnetic Materials Development Laboratory* (introduced by W. S. Byrnes).—Irradiation effects on the properties of ferromagnetic single crystals are being studied. Magnetostriction and anisotropy constants were determined prior to irradiation for alloys of nickel iron, silicon iron, cobalt iron, and cobalt nickel. Order-disorder effects were briefly studied in the alloys having this reaction. The present data for the nickel iron and silicon iron systems agree well with recently published values. The first anisotropy constant, K_1, for the cobalt nickel system as derived from torque curves is similar to old data derived from magnetization curves. However, K_1 for cobalt iron (30, 35, and 45% cobalt) appears to be considerably larger than previously reported. In general, the addition of cobalt to nickel and to iron changes the magnetostriction constants (λ_{100} to λ_{111}) toward large positive values. Thus, λ_{100} increases to 100×10^{-6} for 50% cobalt nickel and to 130×10^{-6} for 45% cobalt iron; λ_{111} increases to 30×10^{-6} for 45% cobalt iron but remains approximately constant for the cobalt nickel alloys.

* Supported by the Aeronautical Research Laboratory, Wright Air Development Center.

M10. Magnetoresistance of Copper. R. L. DOLECEK, R. T. WEBBER, AND J. DE LAUNAY, *U. S. Naval Research Laboratory.*—The magnetoresistance of copper has been measured at 297, 78, and 4.2°K. In a transverse field of 100 kilogauss at room temperature the resistance increased about $\frac{1}{4}$% and within experimental error was a quadratic function of the applied magnetic field. At the lower temperatures the field dependence of the transverse magnetoresistance is considerably less than quadratic and approaches linearity at high fields. Considerable temperature dependence for Kohler's rule was found as well as some deviations attributed to differences in sample purity. Saturation of the longitudinal magnetoresistance at high fields was observed at 4.2°K. The change in longitudinal resistance for saturation is of the order of the initial resistance in zero field and was found to be independent of temperature for the range 2.0 to 4.2°K and of measuring current for the range 0.1 to 2.0 amp. The ratio of the transverse to the longitudinal magnetoresistance of a specimen was found to be a linear function of the applied field. These new features of magnetoresistive behavior can serve to stimulate the development of an adequate theory of longitudinal and transverse magnetoresistance.

M11. Magnetic Susceptibility of Tellurium. F. T. HEDGCOCK, *University of Ottawa, Canada* (introduced by D. K. C. MacDonald).—Results on a number of samples of pure tellurium as well as both *p*- and *n*-type material measured between 4.2°K and the melting point will be presented. Magnetic evidence for the trapping of charge carriers in the extrinsic material can only be seen in the liquid helium region. Effective mass and activation energies are calculated from these results. Band overlap effects have been proposed to explain the Hall effect coefficient inversion at high temperature, and since the magnetic susceptibility is a volume property and independent of assumed electron scattering properties, the high temperature susceptibility results provide additional information on the proposed band overlap.

M12. Neutron Scattering by Paramagnetic MnO. P. K. IYENGAR* AND B. N. BROCKHOUSE, *Chalk River Laboratories.*—The angular distribution of the paramagnetic diffuse scattering[1] from MnO has been measured at four temperatures and two wavelengths. The results show that the couplings of a Mn atom with its first and second Mn neighbors are antiferromagnetic and of the same order (as expected). Energy distributions of the scattered neutrons have been obtained at $Q_0 = (4\pi/\lambda)\sin(\phi/2) = 0.68$, 1.29, and 1.93 A^{-1}, at room temperature and at 320°C. The energy distribution for $Q_0 = 1.29$, near the maximum of the differential cross section, is the narrowest of the three in disagreement with Slotnick[2] but in line with intuitive expectations that peaks in scattered intensity should involve smaller energy transfers than valleys. The distributions have been analyzed approximately into components whose shape and width are independent of Q_0. One component is roughly Gaussian and independent of temperature with an rms energy transfer of 7×10^{-3} ev and intensity proportional to the magnetic form factor $f^2(Q_0)$. The other component has an rms energy transfer $\sim 4 \times 10^{-3}$ ev and intensity proportional to the deviation of the cross section from $f^2(Q_0)$. The two components are connected through Van Hove's theory[3] with self and neighbors time-dependent correlation functions.

* Visiting scientist from Atomic Energy Establishment, Bombay, India.
[1] Shull, Strauser, and Wollan, Phys. Rev. **83**, 333 (1951).
[2] M. Slotnick, Phys. Rev. **83**, 1226 (1951).
[3] L. Van Hove, Phys. Rev. **95**, 1374 (1954).

FRIDAY MORNING AT 9:30

Sheraton Hall

(G. E. UHLENBECK presiding)

Lectures on Parity and Cognate Topics by the Nobel Laureates

MA1. The Law of Parity Conservation and Other Symmetry Laws of Physics. C. N. YANG, *Institute for Advanced Study.* (45 min.)

MA2. Parity Nonconservation and Weak Interactions. T. D. LEE, *Columbia University.* (45 min.)

FRIDAY AFTERNOON AT 1:45

Sheraton Hall

(J. W. BEAMS presiding)

Thermonuclear Enterprises

N1. The Mirror Machine. R. F. POST, *University of California, Livermore.* (45 min.)

N2. The Stellarator Concept. LYMAN SPITZER, JR., *Princeton University.* (45 min.)

N3. High-Energy Steady-State Injection into Thermonuclear Devices: The Luce Ignition Scheme. ALBERT SIMON, *Oak Ridge National Laboratory.* (30 min.)

FRIDAY AFTERNOON AT 1:45

Shoreham, West Ballroom

(GEORGE SNOW presiding)

Pions and Muons

NA1. π^+ Production in Hydrogen by 450-Mev Protons.* L. G. PONDROM, A. V. CREWE, AND U. E. KRUSE, *University of Chicago.*—The external proton beam of the Chicago cyclotron has been used to study the reaction $P+P\rightarrow\pi^++N+P$ at 450 Mev. The reaction $P+P\rightarrow\pi^++D$ was also measured as a check on the equipment. Pions were observed from hydrogen by CH_2-C subtraction at angles of 14°, 20.5°, and 30° in the laboratory. A double focusing wedge magnet gave the momentum distribution of the pions, with an over-all resolution of 1.5% to 2%. A least squares fit of the $P+P\rightarrow\pi^++D$ data in the c.m. system gives $d\sigma/d\Omega\alpha(0.38\pm0.20+\cos^2\theta)$ with $\sigma=1.47\pm0.12$ mb. These results are consistent with other experimental data in this energy region.[1] A least squares analysis of the "unbound" spectra in terms of the phenomenological theory of Brueckner and Watson is in progress. The unbound data are being fitted to *Ss*, *Sp*, *Ps*, and *Pp* spectrum shapes, i.e., both σ_{10} and σ_{11}, in the notation of Rosenfeld.[2] The values of these parameters and the application of the phenomenological theory to this energy region will be discussed.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] T. H. Fields, U. S. Atomic Energy Commission Report, NYO-7103 (unpublished).
[2] A. H. Rosenfeld, Phys. Rev. 96, 139 (1954).

NA2. Pion Production by 1.5-Bev Negative Pions. J. E. CREW* AND R. D. HILL, *University of Illinois.*—The energy spectrum of charged pion secondaries from stars produced in nuclear emulsions by bombardment of *G5* emulsions with 1.5 Bev π^- mesons has been measured. Ionization, range, and, where possible, scattering measurements have been made on all secondary tracks. A total of 309 pions from 472 pion-produced stars was identified. The pion energy spectrum was observed to be sharply peaked between 100- and 150-Mev laboratory pion kinetic energy. The mean pion energy was 148 Mev and three quarters of the pions were in the energy range from 50 to 150 Mev. The multiplicity of charged pions was observed to be 0.65 meson per star. These results are in disagreement with a Monte Carlo calculation made at Los Alamos.[1] However, the use of certain simplifying models and assumptions in the calculation prevented a conclusive test. A Monte Carlo calculation using more recent high energy pion-nucleon data and an isobar model of pion production in independent pion-nucleon collisions has been performed on ILLIAC. This has led to some improvement, but considerable disagreement on the high-energy part of the pion spectrum still exists.

* Now at National Bureau of Standards.
[1] Bivins, Metropolis, Storm, Turkevich, Miller, and Friedlander, Bull. Am. Phys. Soc. Ser. II, 2, 63 (1957).

NA3. Production of π^+ Mesons by Polarized Bremsstrahlung at 240, 335, and 373 Mev.* R. F. MOZLEY, R. E. TAYLOR, AND F. R. TANGHERLINI, *Stanford University.*—We have studied π^+-meson production at 90° c.m. angle and photon energies of 240, 335, and 375 Mev, using polarized bremsstrahlung from the 600-Mev electron beam of the Stanford linear accelerator. The polarized bremsstrahlung beam was obtained by selecting the bremsstrahlung produced in a 3-mil aluminum radiator at an angle of approximately 1/1000 radian from the electron beam direction. To estimate the amount of polarization the aperture function and a measured value of the multiple scattering are folded into the polarization calculated by May[1] using a relativistic small angle approximation. The ratio of meson production along and at right angles to the electric field vector is measured and compared with the values predicted by the relativistic dispersion relation.[2]

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.
[1] M. May, Phys. Rev. 84, 265 (1951).
[2] Chew, Goldberger, Low, and Nambu, Phys. Rev. 106, 1345 (1957).

NA4. Relative Angular Distribution of Photopions from Hydrogen.* ROBERT W. KENNEY, EDWARD A. KNAPP, AND VICTOR PEREZ-MENDEZ, *University of California, Berkeley.*—The relative angular distribution of positive pions from the reaction $\gamma+p\rightarrow\pi^++n$ has been measured for 290 Mev photon energy, by use of the 340-Mev bremsstrahlung beam from the Berkeley synchrotron. The pions were detected by a counter telescope and its associated $\pi-\mu$ gear described previously.[1] Table I gives the results. Absolute values are

TABLE I.

$\theta_{c.m.}$	23°	40°	50°	70°	90°	115°	140°	160°
$\frac{d\sigma}{d\Omega}$ (μb/sterad)	7.87 ±0.37	8.97 ±0.40	12.10 ±0.43	16.00 ±0.52	19.90 ±0.46	19.40 ±0.55	16.50 ±0.40	13.50 ±0.60

obtained by normalizing the relative distribution to the California Institute of Technology magnet data at $\theta_{c.m.}=120°$. The listed standard deviations are counting errors only. Our measurements agree, within statistics, with the 290-Mev California Institute of Technology magnet data in the angular range forward of $\theta_{c.m.}=120°$ and with the 290-Mev California Institute of Technology counter data at angles greater than $\theta_{c.m.}=90°$. In the regions of disagreement between the two California Institute of Technology experiments, our results agree with the lower of their cross-section values. The data in Table I will be compared with measurements at neighboring photon energies and the results will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Imhof, Kalibjian, and Perez-Mendez, Rev. Sci. Instr. (to be published).

NA5. Photoproduction of Pion Pairs.* MATTHEW SANDS AND DAVID ELLIOT, *California Institute of Technology.*—The yield of negative pions from the interaction of high-energy photons with the proton has been measured in a previous experiment.[1] The apparatus used for that work has been expanded to permit the simultaneous observation of both pions emitted from the interaction. The negative pion is detected in the magnetic, momentum spectrometer, as before. The positive pion is observed in a telescope of three scintillation counters separated by suitable lead absorbers, so that a rough measurement of the pion energy is made. Pion-pion coincidences have been observed. Preliminary results will be reported.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] M. Bloch and M. Sands, Phys. Rev. **108**, 1101 (1957).

NA6. Photoproduction of Neutral Pions from Hydrogen.* H. H. BINGHAM AND A. B. CLEGG, *California Institute of Technology.*—A spectrometer for high-energy gamma rays has been developed using a thallium chloride crystal 5.5 in. (13.4 radiation lengths) long and 5.75 in. in diameter, observing the Čerenkov light from the electrons in the gamma-ray shower. It has been calibrated with monoenergetic electrons of energies up to 1 Bev. At energies above 350 Mev the resolution (full width at half-maximum) is 25% for electrons within one inch of the axis. At lower energies the resolution is worse, presumably due mainly to statistical fluctuations in the number of electrons produced at the photocathode. This instrument is being used to observe the high-energy gamma rays from the decay of neutral pions photoproduced from a hydrogen target by the bremsstrahlung beam of the Caltech synchrotron. The yield from a range of incident photon energy is obtained by the photon difference method. From the resulting pulse-height spectrum it is possible to determine separately the yields of neutral pions from both single and multiple production processes. Results will be presented.

* This work was supported in part by the U. S. Atomic Energy Commission.

NA7. π-P Scattering at Low Energies. S. W. BARNES, B. ROSE, G. GIACOMELLI, J. RING, AND K. MIYAKE, *University of Rochester.*—Pion proton differential scattering cross sections have been measured at 41.5 Mev at six angles for positive pions and at five for negative pions. A phase-shift analysis has been made of a combination of the above data with the positive pion differential cross sections recently determined at 24.8 Mev by Miller and Ring,[1] and those at 31.5 Mev by Johnson and Camac,[2] and the earlier positive and negative pion cross sections measured in the vicinity of 60 Mev by Bodansky, Sacks, and Steinberger.[3] For this energy range the four phase shifts α_{33}, α_3, α_1, and α_{31} seem to be determined to an accuracy of 2.5%, 4%, 8%, and 12%, respectively, while the phases α_{13} and α_{11} are certainly small.

[1] N.Y.O. 2168.
[2] N.Y.O. 2169.
[3] Bodansky, Sacks, and Steinberger, Phys. Rev. **93**, 1367 (1954); **90**, 996, 997 (1953).

NA8. Recoil Proton Polarization in π^-+p Scattering.* J. KUNZE, T. A. ROMANOWSKI, AND J. ASHKIN, *Carnegie Institute of Technology.*—Measurements have been made of the polarization of the recoil proton from 223 Mev π^- mesons scattered from hydrogen. The second proton scattering occurs in a carbon polarization analyzer located in a counter-controlled fast-cycling cloud chamber. The measurements have been made at proton recoil angles of 15° and 30° in the laboratory. About 18 000 pictures have been taken, of which about 1300 are useful scatterings. The pictures are measured by stereoscopic reprojection. The results are analyzed using polarization data of protons on carbon,[1] and a computer to perform a maximum likelihood analysis. The polarization value obtained at 15° from 568 events is -0.08 ± 0.12 in the direction of the cross product between recoil proton and incident pion momenta. This excludes one set of phase shifts of the Yang type. Results at 30° will be presented and an attempt made to resolve further phase-shift ambiguities.[2]

* This work supported by the U. S. Atomic Energy Commission.
[1] Dickson and Salter, Nuovo cimento **6**, 235 (1957).
[2] Ashkin, Blaser, Feiner, and Stern, Phys. Rev. **105**, 724 (1957).

NA9. π^--P Interactions at 440 Mev. J. BALLAM, *Michigan State University and Brookhaven National Laboratory,** AND R. R. CRITTENDEN, J. H. SCANDRETT, W. D. SHEPHARD, AND W. D. WALKER, *University of Wisconsin and Brookhaven National Laboratory.*—Analysis of photographs taken with a propane bubble chamber exposed to a 440 Mev π^- beam at the Cosmotron has yielded the following preliminary results for hydrogen events: $\sigma_{el}=12$ mb, $\sigma_{exch}=14$ mb, $\sigma_{inel}=2.5$ mb with statistical errors of about 15%. These total cross sections have been normalized to the total π^--p cross section of Cool *et al.*[1] The angular distribution of the elastic scatters in the c.m. system will be presented.

* Supported in part by the National Science Foundation.
† Supported in part by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] Cool, Piccioni, and Clark, Phys. Rev. **103**, 1082 (1956).

NA10. π^--P Interactions at 600 Mev. W. D. WALKER, P. R. CRITTENDEN, J. H. SCANDRETT, AND W. D. SHEPHARD, *University of Wisconsin and Brookhaven National Laboratory,** AND J. BALLAM, *Michigan State University and Brookhaven National Laboratory.*†—Preliminary measurements have been made of π^--P collisions in the energy region around 600 Mev using a propane bubble chamber. Data are available on the differential elastic scattering at 600 Mev. The preliminary results show very little scattering into the backward hemisphere in the center-of-mass system. This is in marked contrast to results in the 1-Bev region. The results on all the processes are $\sigma_{el}=18$ mb, $\sigma_{exch}=6.4$ mb, $\sigma_{inel}=11$ mb. Almost all of σ_{exch} is an elastic charge exchange process.

* Supported in part by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
† Supported in part by the National Science Foundation.

NA11. Positive Pion Scattering from Hydrogen at 31.5 Mev.* W. B. JOHNSON† AND M. CAMAC,‡ *University of Rochester.*—The differential scattering cross section for positive pions on hydrogen has been measured at three laboratory angle, 60°, 90°, and 135°, for an incident pion energy of 31.5 ± 1.5 Mev. The mesons were incident on a target containing liquid hydrogen. The scattered particles were detected by three counter telescopes placed at the appropriate positions. Additional discrimination against background was provided by pulse-height analysis on any two sets of counters. Phase shifts have been obtained by analyzing the data in the usual way. We find that $\alpha_3=-3.72°\pm0.38°$, $\alpha_{33}=2.77\pm0.32°$, and $\alpha_{31}=-0.61\pm0.24°$. Expressed in terms

of the scattering lengths these results yield $a_3 = -0.108 \pm 0.011$ and $a_{31} = 0.048 \pm 0.006$.

* This work supported by the U. S. Atomic Energy Commission.
† Present address: Tonawanda Laboratory, Linde Company, Tonawanda, New York.
‡ Present address: AVCO Research Laboratory, Everett, Massachusetts.

NA12. Dispersion Relations and π-Meson Scattering.* J. HAMILTON, *Cornell University.*—The discrepancy[1] between the dispersion relations for π^- scattering on protons and the experiments in the 120–220 Mev range can be reduced by a careful evaluation of the dispersion integral.[2] The inaccuracies in the experimental data are examined, and we find that the remaining discrepancy cannot be removed without contradicting at least one of several apparently accurate experimental results. Electromagnetic effects, charge exchange effects, the $(\pi^- - \pi^0)$ mass difference, or a possible breakdown of charge independence can be ruled out as causes of the discrepancy. (An independent relation to check the agreement of charge exchange scattering with charge independence is suggested.) Experimental[3] results on π^- elastic scattering in the 300–340 Mev region show considerable disagreement with the dispersion relation.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. Puppi and A. Stanghellini, Nuovo cimento 5, 1305 (1957).
[2] G. Salzman and H. Schnetzer (private communication).
[3] S. M. Korenchenko and V. G. Zinov, Padua Conference (1957).

NA13. $\pi^- - P$ Scattering and the Dispersion Relations.* H. Y. CHIU, *Cornell University.*—In a recent paper by Hamilton[1] it was pointed out that the dispersion relation for $\pi^- - P$ scattering is still in disagreement with the experiments. A dispersion relation with less dependence on the coupling constant f^2 is obtained by choosing an energy $\omega > \mu$ for the subtraction. Agreement with the experimental results up to laboratory energy 220 Mev is obtained, if one increases the first resonance peak of σ_-^{total} by about 7 mb (i.e., by 10%) as conjectured in reference 1. The inadequacy of the experimental error of $D_-(\omega)$ as evaluated by Puppi and Stanghelini[2] will be discussed, together with a discussion on the total cross section as obtained by a phase-shift analysis.

* Supported in part by the joint program of the Office of the Naval Research and the U. S. Atomic Energy Commission.
[1] J. Hamilton, Bull. Am. Phys. Soc. Ser. II, 2, 198 (1958), preceding abstract.
[2] G. Puppi and A. Stanghelini, Nuovo cimento 5, 1305 (1957).

NA14. Modification of the Decay Rates of Negative Muons by Binding.* J. C. SENS, R. A. LUNDY, R. A. SWANSON, V. L. TELEGDI, AND D. D. YOVANOVITCH, *University of Chicago.*—The *decay* rate, $\lambda(Z)$, of a μ^- in its *1s* orbit around a charge Ze will differ from the free decay rate $\lambda(0)$. An effect due to the decrease in available energy and to the Doppler shift of the decay spectrum has been predicted.[1] On this basis, for a point nucleus, $\lambda(Z) = [1 - \eta\alpha^2 Z^2]\lambda(0)$; Khuri finds $\eta = 5.16$. The ratio $R \equiv \lambda(Z)/\lambda(0)$ is being investigated by two methods: (a) μ^+ and μ^- beams of identical momenta and similar range distribution are stopped in light (Z_1) and heavy (Z_2) targets of equal stopping power. The decay electron numbers and time distribution are measured simultaneously.[2] The μ^+ runs are used to eliminate absolute efficiencies. Assuming $\lambda(Z_1) = \lambda(0)$, one obtains $R(Z_2)$. Using $Z_1 = 4$ and 6, we find $R(26) = 1.22 \pm 0.10$, and $R(82) = 0.68 \pm 0.10$. (b) μ^- are stopped in multilayer targets of Z_1 and Z_2; the electron time distribution is then analyzed into two components. The ratio of μ^- stopped in either material is calculated or measured. This yields $R(26) = 1.15 \pm 0.06$. The fact that $R(26) > 1$ and $R(82) < 1$ is attributed to Coulomb effects on the electron, treated as unperturbed in reference 1.

* Research supported by joint contract of the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] C. E. Porter and H. Primakoff, Phys. Rev. 83, 849 (1951); Muto *et al.*, Progr. Theoret. Phys. 8, 13 (1952); N. D. Khuri and A. S. Wightman (private communication).
[2] Sens *et al.*, Nuovo cimento (to be published).

NA15. Application of "Stroboscopic Coincidences" to Muon Precession.* A. LUNDY, J. OREAR, J. C. SENS, R. A. SWANSON, V. L. TELEGDI, AND D. D. YOVANOVITCH, *University of Chicago.*—As an alternative to resonance methods[1] for measuring precisely the muon magnetic moment, this method[2] is now being applied here; the muons are stopped in a suitable target and made to precess in a plane perpendicular to a static field B_0 with a frequency ω_0. Muons and electrons are detected by coincidence telescopes. Each muon signal turns on a phase-stable rf oscillator of frequency ω for a period of 6 μsec, and coincidences are made between electrons and the negative half-cycles of the oscillator signal. An extremum in this coincidence rate occurs when $\omega_0 = \omega$. Its full width at half-extremum is predicted to be $2/\tau$, $\tau \equiv$ muon mean life. Experiments are now in progress at $\omega_0 = 4$ Mc and at $\omega_0 = 49$ Mc and should yield the moment to an accuracy of 0.4% and 0.04%, respectively, by direct comparison with the proton resonance frequency in the same B_0. Results will be reported.

* Research supported by joint contract of the Office of Naval Research and U. S. Atomic Energy Commission.
[1] Coffin, Garwin, Lederman, Penman, and Sachs, Phys. Rev. 106, 1108 (1957); also Bull. Am. Phys. Soc. Ser. II, 3, 34 (1958).
[2] V. L. Telegdi, Rev. Sci. Instr. (to be published).

FRIDAY AFTERNOON AT 2:00

Sheraton-Park, Continental Room

(K. L. DUNNING presiding)

Nuclear Reactions II

P1. Study of the $C^{14}(d,p)C^{15}$ and $C^{14}(d,t)C^{13}$ Reactions.* W. E. MOORE AND J. N. MCGRUER, *University of Pittsburgh.*—Proton groups have been observed corresponding to the ground state and to levels at 0.7 ± 0.1 Mev and 6.2 ± 0.15 Mev in C^{15}. Triton groups have also been observed corresponding to the ground state and to the 3.68 and 3.86-Mev levels of C^{13} at $\theta_L = 14°$, the intensities of these three groups are in the ratio 1:0.2:0.014, respectively.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of Office of Naval Research and the U. S. Atomic Energy Commission.

P2. Absolute Cross-Section for $N^{14}(p,p)N^{14}$.* R. A. DOUGLAS, R. R. CARLSON, S. BASHKIN, AND C. BROUDE, *State University of Iowa.*—Elastic scattering cross sections for protons on N^{14} have been measured for bombarding energies from 900 kev to 4000 kev and for angles of 90, 125.3, 149.4, and 160.9° in the center-of-mass system. Anomalies were observed at the bombarding energies previously reported.[1] A large anomaly was observed at a bombarding energy of 3910 kev. This corresponds to the excited state at 11.00 Mev in O^{15} which was observed in the $N^{14}(p,p'\gamma)N^{14}$ reaction.[2] Scattering

was observed with a natural nitrogen gas target. A spread of 0.25% in the proton energy was obtained using 1000 A nickel entrance windows. A 7-mil thick CsI(Tl) crystal detector was used and pulses were counted using a 256-channel pulse-height analyzer. Absolute cross-section measurements were made. Measurements of the known elastic scattering X sections of hydrogen, helium, carbon, and oxygen checked to within $\pm 2\%$. A comparison of the present measurements with other measurements of the $N^{14}(p,p)N^{14}$ cross section will be made.[3]

* Supported in part by the U. S. Atomic Energy Commission.
[1] Bashkin, Carlson, and Jacobs, Bull. Am. Phys. Soc. Ser. II, 1, 212 (1956).
[2] Bair, Cohn, Kington, and Willard, Phys. Rev. 104, 1595 (1956).
[3] Ferguson, Clark, Gove, and Sample, Chalk River Project Report PD-261, 1956 (unpublished). G. W. Taulfest and S. Rubin, Phys. Rev. 103, 196 (1956). Hagedorn, Mozer, Webb, Fowler, and Lauritsen, Phys. Rev. 105, 219 (1957). Bolmgren, Freier, Likely, and Famularo, Phys. Rev. 105, 210 (1956).

P3. Absolute Cross Sections for $N^{15}(p,p)N^{15}$, $N^{15}(p,\alpha)C^{12}$, $N^{15}(p,\alpha)C^{12}$.* R. R. CARLSON, R. A. DOUGLAS, S. BASHKIN, AND C. BROUDE, *State University of Iowa.*—Absolute cross sections for elastic scattering and the $p\alpha$ reactions to the ground and first excited states of C^{12} have been measured using the apparatus described in the previous paper. The nitrogen gas was enriched up to 98.2% N^{15}. Proton energies from 650 kev to 3650 kev and laboratory angles of 66.7, 86.2, 131.1, 140.1, 151.7 and 159.5°, were used. Present results agree with those previously obtained on the $N^{15}(p,\alpha\gamma)C^{12}$ and $N^{15}(p,\alpha)C^{12}$ reactions.[1,2] The yield of the 4.4-Mev gamma ray C^{12*} was measured again with a NaI(Tl) counter at a fixed position. This yield served to guarantee the relative accuracy of the energy scales for the different yield curves taken on the particles. The gamma counter also detected the 13-Mev gamma rays from $N^{15}(p,\alpha)O^{16}$. Angular distributions of the charged particles were measured at resonances.

* Supported in part by the U. S. Atomic Energy Commission.
[1] S. Bashkin and R. R. Carlson, Phys. Rev. 106, 261 (1957).
[2] Jacobs, Bashkin, and Carlson, Bull. Am. Phys. Soc. Ser. II, 1, 212 (1956).

P4. Angular Distribution of $N^{15}(d,\alpha)C^{13}$ Reaction.* V. K. FISCHER AND G. E. FISCHER, *Columbia University and Brookhaven National Laboratory.*—The angular distribution of the $N^{15}(d,\alpha)C^{13}$ reaction has been measured at the Brookhaven National Laboratory 60-in. cyclotron with a deuteron bombarding energy of 21 Mev. The equipment used has been described previously. Only the reaction leading to the ground state could be adequately resolved from reactions leading to other states in C^{13} and from N^{14} contamination of the sample with the proportional counter-CsI counter telescope. The differential cross section varied between 350 and 20 microbarns/steradian, with a minimum at 50° and a maximum at 70° in the cm system. These data, as well as the previously obtained $N^{14}(d,\alpha)C^{12}$ angular distributions have been fit with a direct interaction theory.

* This work partially supported by the U. S. Atomic Energy Commission.

P5. Mechanisms for $O^{16}+He^3$ Reactions at Low Energies. D. A. BROMLEY, J. A. KUEHNER, AND E. ALMQVIST, *Atomic Energy of Canada Limited.*—Excitation curves for the alpha group to the O^{13} ground state and for proton groups to the first 6 states of F^{18} have been examined in the incident He^3 energy range from 2.0 to 5.4 Mev. Pronounced resonance structure is observed in all cases; in particular, all groups appear to be resonant at $E_{He^3}\sim 2.45$ Mev corresponding to an excitation of ~ 10.48 Mev in Ne^{19}. Angular distributions of both alphas and protons have been examined in the vicinity of this resonance. The alpha distributions on resonance are approximately symmetric about 90° in the center-of-mass system suggesting a compound system reaction mechanism; all show large negative $P_2(\cos\theta)$ components. It is not possible to fit these distributions assuming a single Ne^{19} state with $j \leq 11/2$. At energies off the resonance the distributions are asymmetric about 90° in the center-of-mass system, in some cases having forward maxima suggestive of a direct interaction mechanism. Proton angular distributions are under study to obtain further information on the reaction mechanisms and on spin assignments to some of the F^{18} excited states.

P6. Elastic Scattering of Alpha Particles by O^{16}.* L. C. MCDERMOTT, K. W. JONES, H. SMOTRICH, AND R. E. BENEŠSON, *Columbia University.*—Absolute cross sections for the scattering of alpha particles by O^{16} have been determined at laboratory energies from 3.9 Mev to 5.5 Mev at center-of-mass angles of 90.0, 125.3, 140.8, and 168.9°. A Van de Graaff accelerator and a differentially pumped gas scattering chamber were used for the measurements. The results of a preliminary phase shift analysis are given in Table I.

TABLE I.

E_α(Lab) Mev	Γ(cm) kev	J, π	$\gamma\lambda^2$ $3/2(\lambda^2/\mu\pi)$	Ne^{20*} Mev
~4.8	~1300	0+	~70%	~8.6
5.01	4	1−	0.23	8.75
~5.1	~1200	2+	~95	~8.8
5.11	≤4	(5−)	...	8.83
5.19	20	1−	1.0	8.90
5.44	8	4+	3.9	9.10

* This work partially supported by the U. S. Atomic Energy Commission.

P7. Level Assignment in O^{18} from the Reaction $C^{14}(\alpha,\gamma)O^{18}$. H. E. GOVE AND A. E. LITHERLAND, *Atomic Energy of Canada Limited.*—Angular distribution measurements of capture gamma rays at two resonances in the reaction $C^{14}(\alpha,\gamma)O^{18}$ have permitted the following spin and partity assignments to be made to levels in O^{18}; 0 Mev (0+), 1.99 Mev (2+), 3.58 Mev (4+), 7.12 Mev (4+), and 7.62 Mev (1−) assuming both C^{14} and the alpha particle to have spin 0+. Independent measurements at Wisconsin[1] agree with the first two and the last while (d,p) stripping results at Michigan[2] agree with the first three. Coincidence measurements showed no evidence for a ground-state transition from the level at 3.58 Mev (less than 3% of the cascade). The quantity $\Gamma_\alpha\Gamma_\gamma/\Gamma$ for the primary $E2$ transition to the first excited state from the g wave resonance at $E_\alpha = 1.13$ Mev ($E_{EX} = 7.12$ Mev) is approximately 0.01 ev while the ground-state $E1$ transition from the p wave resonance at $E_\alpha = 1.78$ Mev ($E_{EX} = 7.62$ Mev) is about 0.08 ev. The pertinence of the results to current nuclear models will be discussed.

[1] W. R. Phillips (private communication).
[2] O. M. Bilaniuk and P. V. C. Hough, Phys. Rev. 108, 305 (1957).

P8. Scattering of 19-Mev Alpha Particles by C^{12}.* J. R. PRIEST, J. C. CORELLI, E. BLEULER, AND D. J. TENDAM, *Purdue University.*—The elastic and inelastic scattering of 19-Mev alpha particles from a gaseous target of propane has been measured using nuclear plates as detectors. The elastic angular distribution, measured every 2.5° from 13.3° to 161.3° (c.m.), exhibits the usual diffraction-like pattern with deep minima at 29.2, 44.8, 73.8, 88.8, 111.9, 135.6, and 160° (c.m.). We do not observe the anomaly in the elastic angular distribution reported by Watters at 30.5-Mev incident energy. The minima are more closely spaced for C^{12} than for O^{16} in the c.m. system which would indicate that the interaction radius for C^{12} is greater than that of O^{16}. The angular distribution from the 4.43-Mev (2+) level, measured from 15° to 121° (c.m.), exhibits a forward peak and three pronounced minima at 47.2, 80.6, 117.9° (c.m.). Direct-interaction analysis on this distribution yields a value of 5.5×10^{-13} cm for the interaction radius. The scattering from the 9.61-Mev state exhibits

a smooth decrease in cross section with forward peaking and no pronounced structure in the region of angles measured (20° to 78° c.m.). The scattering cross sections from the 7.65-Mev (0^+) level are an order of magnitude smaller than those observed from the 4.63 and 9.61-Mev levels. This is consistent with the inelastic scattering of 19-Mev alphas from the 6.74-Mev level (0^+) of neon.

* Supported in part by the U. S. Atomic Energy Commission.

P9. Scattering of 19-Mev Alpha Particles by S^{32} and O^{16}.* J. C. CORELLI, E. BLEULER, D. J. TENDAM, *Purdue University.*—The elastic and inelastic scattering of 19-Mev alpha particles from gaseous targets of H_2S and O_2 has been measured. For S^{32} the angular distribution of the elastic scattering and the inelastic scattering from the 2.24-Mev (2^+) level was measured from 11.3° to 171.3° (c.m.) at 2.5° angular intervals. Both angular distributions exhibit diffraction-like patterns. The elastic distribution contains pronounced minima at 41.4, 60, 78.9, 103.8, 126.9, 145.2, and 165° (c.m.). The elastic scattering cross section varies between 54 000 mb at 11.3° and 0.4 mb at 80° in the c.m. system. The angular distribution from the 2.24 Mev (2^+) level of S^{32} exhibits a strong forward peaking with pronounced minima at 33.9, 51.8, 73.5, 96.7, 120.1, 145.0, and 165.3° (c.m.). An estimation of the interaction radius from this distribution yields the value 6.5×10^{-13} cm and 7.16×10^{-13} cm is obtained for the elastic scattering. The angular distribution of the inelastic scattering of alpha particles from the 8.87 Mev (2^-) level of O^{16} was measured from 13.9° to 105.6° (c.m.). The angular distribution from this state will be compared with that from other excited states of O^{16} previously reported.[1] A survey of our measurements of the elastic scattering of alpha particles from light to medium heavy nuclei will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Corelli, Bleuler, and Tendam, Bull. Am. Phys. Soc. Ser. II, 2, 34 (1957).

P10. Low-Lying Excited States of Na^{22}. G. M. TEMMER AND N. P. HEYDENBURG, *DTM, Carnegie Institution of Wasington.*—In an effort to locate the first $T=1$, $T_z=0$ state of Na^{22} we have extended our study of the $F^{19}(\alpha,n\gamma)Na^{22}$ reaction which previously yielded a first excited state at 593 kev.[1] Using a He^+ beam energy of 3.7 Mev, we found that a 73 ± 1-kev gamma ray was in delayed coincidence with the 593-kev transition. We measured the half-life of the latter state to be 0.266 ± 0.009 μsec. Since the ground state has character 3^+, 0^+ (and hence $T=1$) is definitely ruled out for the 593-kev level ($\sim10^6$ times too fast for an $M3$ transition). Upon bombarding with 5.7 Mev He^{++} both the 73-kev and 593-kev radiations appear in coincidence with a 1.4-Mev transition, again yielding the above lifetime for the 593-kev state, and also showing preliminary evidence for a ~0.04 microsecond half-life for the 73-kev transition. We are trying to determine whether this higher excited state at about 2.07 Mev also feeds the 593-kev state directly, or only in triple cascade via the 73-kev gamma. We believe that the new state at 666 ± 4 kev above ground is the lowest $T=1$ state in Na^{22}. It is the only one in this region of excitation not found in the self-conjugate reaction $Mg^{24}(d,\alpha)Na^{22}$.[2] Energies (in kev) of states in Na^{22} we observe, together with some tentative spin-parity assignments are as follows: $0-3^+$; $593-(1^+)$; $666-(0^+)$; 890; 2070.

[1] N. P. Heydenburg and G. M. Temmer, Phys. Rev. 94, 1252 (1954).
[2] C. P. Browne and W. C. Cobb, Phys. Rev. 99, 644(A) (1955).

P11. Gamma Rays from $Na^{23}+p$.* T. H. KRUSE, R. D. BENT, AND L. J. LIDOFSKY, *Columbia University.*—An investigation has been made of the gamma rays emitted from low-lying states of Na^{23} and Ne^{20} following proton bombardment of Na^{23} using the Columbia Van de Graaff accelerator. Spectra of the prominent high-energy gamma lines have been determined at several bombarding energies up to 6 Mev using a 3-crystal pair spectrometer. In addition, $\gamma-\gamma$, $p'-\gamma$, and $\alpha-\gamma$ coincidence studies have been performed to determine the relative intensities of gamma rays originating from individual states of Na^{23} up to 3.9 Mev excitation and from the 4.2- and 4.9-Mev states in Ne^{20}. Wherever possible, branching ratios have been calculated and will be presented.

* This work partially supported by the U. S. Atomic Energy Commission.

P12. Linear Polarization of Gamma Rays from Certain Nuclear Reactions. A. E. LITHERLAND AND H. E. GOVE, *Atomic Energy of Canada Limited.*—The linear polarization of the 1.37-Mev gamma rays from the reaction $Mg^{24}(pp'\gamma)$ has been studied using the Compton scattering technique. At the 2.01- and 2.40-Mev resonances the polarization-direction correlations gave agreement with previous spin and parity assignments for the first excited state of Mg^{24}. The gamma rays at each resonance were nearly 100% linearly polarized at 90° to the proton beam. The linear polarizations of the 0.94-Mev gamma rays from the first excited state of F^{18} and of the 1.64-Mev gamma rays from the second excited state of N^{14} have been studied using the $O^{16}(He^3,p)F^{18}$ and $C^{12}(He^3,p)N^{14}$ reactions. The study of the 0.94-Mev gamma ray from F^{18} was stimulated by the work in this laboratory of F^{18} [1] and the linear polarization measurements in this case were carried out in collaboration with the authors of that work. The 0.94-Mev state in F^{18} was shown to have the same parity as the ground state. Linear polarization measurements also demonstrated that the 3.95-Mev state in N^{14} has the same parity as the first excited state.

[1] Almqvist, Bromley, and Kuehner, Bull. Am. Phys. Soc. Ser. II, 3, 27 (1958).

P13. Angular Correlation in the Inelastic Scattering of Protons by Mg^{24}.* H. YOSHIKI AND R. SHERR, *Princeton University.*—Previous measurements of (p',γ) angular correlation in $C^{12}(p,p')C^{12*}$ for 17.5-Mev protons[1,2] showed strong evidence of direct interaction process.[3] We have measured the angular correlation for the first excited state of Mg^{24} (1.37 Mev, $2+$) using 16.6-Mev protons. For $\theta p'=30°$, 42.5° and 70° the result shows that the correlation functions are represented fairly well by the simple Born approximation calculation, $\sin^2(\theta_\gamma-\theta_R)$, as was the case in C^{12}. However, at larger angles, namely, $\theta p'=95°$, 120°, and 150°, changes in the shapes of correlation curves are observed, while the minima of the curves remain at θ_R, the direction of the recoil nucleus. It becomes necessary to introduce a contribution from a $\sin^2(\theta_\gamma-\theta_R)$ term to fit the observed curves. Theoretical calculations[3,4] including exchange amplitude and distortions lead to a correlation of the form $a+b\sin^2\theta+c\sin^2\theta$, independently of models; c can be appreciable in certain cases.[4] The strong correlations observed at all proton angles including 150° preclude any appreciable contribution to this reaction by an incoherent "compound nucleus" process.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] R. Sherr and W. F. Hornyak, Bull. Am. Phys. Soc. Ser. II, 1, 197 (1956).
[2] C. A. Levinson and M. K. Banerjee, Ann. Phys. 2, 508–510 (1957).
[3] Reference 2, p. 471.
[4] J. Sawicki (private communication).

P14. Inelastic Proton Scattering from Mg^{24} and Cr^{52}, 3.5–7 Mev.* FREDERICK D. SEWARD, *University of Rochester.*—Inelastically scattered protons leaving Mg^{24} and Cr^{52} in their first excited states have been studied to see if the reaction goes via compound nucleus formation or by a direct interaction. Targets approximately 150 kev thick were used with the hope of averaging over resonances. $d\sigma/d\omega$ (90°) was measured with proton energies from 3.6 to 7.2 Mev. Some resonances

are seen in Al^{28}. Angular distributions of inelastic protons and angular correlations between inelastic protons and the resulting γ ray have been taken at several energies. Angular distributions for Mg are not symmetric about 90°. Those from Cr are almost isotropic, Angular correlations for Mg at 7.1 Mev are symmetric about the recoil nucleus angle and have the form predicted by Satchler† for a direct interaction. Those for Mg at lower energy and those for Cr are only partially of this form. Results will be compared with theories of both processes.

* Supported in part by the U. S. Atomic Energy Commission.
† G. R. Satchler, Proc. Phys. Soc. (London) **A68**, 1037 (1955).

FRIDAY AFTERNOON AT 2:00

Sheraton-Park, Caribar-Mural Room

(T. D. LEE presiding)

Theoretical Physics III, Including Statistical Theory and Low-Temperature Theory

PA1. Metastability and Metric Decompossbility. JEROME ROTHSTEIN, *Edgerton, Germeshausen & Grier, Inc.*—In theoretical discussions of cooperative phenomena or phase change by statistical methods the usual approaches (e.g., by grand canonical ensembles) usually avoid questions of metastability. The effect is to average over several groups of states where groups may be practically inaccessible from each other in times available for experiments, thereby blunting the sharpness of transitions. It is proposed that at least in some cases of this sort the energy surface consists of two or more effectively disconnected pieces of positive measure, the effect of metastability being to restrict ergodic wandering of the representative point to one component. As the transition temperature is approached from below, say, the components increase in size and the connecting "channels" grow permitting greater mutual accessibility, i.e., the metric decomposability of the energy surface goes over to the ordinarily assumed indecomposability. Possible application to order-disorder transformations, to nucleation and growth of order and crystals, to structural hysteresis and annealing effects will be indicated. A simple explanation of the maximum ordering rate temperature in Cu_3Au and why a simple kinetic treatment of relaxation[1] in ordered Cu_3Au has been so successful quantitatively is proposed in terms of this viewpoint.

[1] J. Rothstein, Phys. Rev. **94**, 1429(A) (1954).

PA2. Long and Short Range Part Separation for the Classical Partition Function. A. A. BROYLES, *The RAND Corporation.*—The many body integral of the Boltzmann factor over all configurations of the particles of the system may be evaluated by integrating over the cell occupation numbers $n_{\mathbf{R}}$ when the volume of the system is divided into infinitesimal cells whose centers are specified by the $\mathbf{R}$ vectors. Such an integration is possible with the aid of a Jacobian J defined by the $\int\cdots\int f\pi_i d\tau_i = \int\cdots\int fJ\pi_{\mathbf{R}} dn_{\mathbf{R}}$, where f is an arbitrary function of the coordinates of the system. This Jacobian is sharply peaked in $n_{\mathbf{R}}$ space so that it will limit the $n_{\mathbf{R}}$'s to integer values. If f is the Boltzmann factor, it may be factored into rapidly and slowly varying parts by separating the potential energy into short and long range parts. The short range part may then be combined with the J. The moments of this rapidly varying combination may be obtained with the aid of the above equation so that it may be approximated by such a smoothly varying function of the $n\mathbf{R}$'s as to allow the evaluation of the original integral.

PA3. Interpolation Method for the Many Body Problem.* GEORGE J. YEVICK AND JEROME K. PERCUS, *Stevens Institute of Technology.*—We seek a canonical transformation from the strongly coupled many body system (which we know) to the intermediate coupling problem. By an intermediate coupling solution, we mean one that is correct to a preassigned order of perturbation and which at the same time is valid for any variation of the mass and force constants characterizing the strong coupling limit. The method for achieving this solution in the classical problem (which serves as a prototype for the quantum mechanical solution) is patterned after the adiabatic theorem of Gell-Mann and Low, and results in an "*S*-matrix" type of formulation. The computation is facilitated by a diagrammatic analysis which in the classical case involves sequences of "trees." If the required order of perturbation is of the second order, the trees reduce to "strings." The string diagrams may be partially summed leading to irreducible diagrams. The irreducible diagrams cannot be summed directly, but are found to satisfy a simple integral equation. For a restricted class of perturbations, the integral equation can be solved, but in general it is necessary to make a further approximation still maintaining the order of the perturbation. Applications, such as computation of collective oscillating variables, are now being considered.

* Supported by the Office of Naval Research.

PA4. The Equation of State for Classical Statistics.* JEROME K. PERCUS AND GEORGE J. YEVICK, *Stevens Institute of Technology.*—The principal problems of classical equilibrium statistical mechanics can be solved if the two body distribution function is known. We shall present a self-consistent formulation for determining the correlation function with the aid of collective coordinates. One can readily show that, without altering the value of a predetermined sequence of fourier coefficients of the two body correlation function, the actual potential may be replaced by an effective temperature dependent potential which contains these fourier coefficients alone. This effective potential is computed by means of an identity involving the average value of a product of tightly distributed functions. On the other hand, by virtue of the same identity and relations existing between collective coordinates and the correlation function, one can establish a second connection between the potential and the correlation function. There results an integral equation which is not linear but is extremely simple in form. If this integral equation is solved by a virial expansion, the first three virial coefficients are exactly reproduced, while the fourth is nearly correct, as evidenced by numerical results for the case of hard spheres. For long range forces, the leading terms are again exactly reproduced; a wide spectrum method is thereby obtained.

* Supported by the Office of Naval Research.

PA5. Transport Phenomena in a Fluid of Polyatomic Molecules. JOHN S. DAHLER, *Wright-Patterson Air Force Base.*—A statistical derivation is given for the equations of hydrodynamics in a fluid composed of polyatomic molecules. In the limit of zero density the hydrodynamical relationships

reduce to those derived by Curtiss[1] for a dilute gas of rigid nonspherical molecules and, in general, the hydrodynamical description of the fluid closely resembles that discovered by Grad[2] in his phenomenological approach to this same problem. Our statistical theory has the advantage, however, that it provides a starting point for a more systematic study of nonequilibrium processes in polyatomic fluids. Because of the noncentral intermolecular forces it is found that, in contrast to the situation for monatomic fluids, the pressure tensor is not symmetric and that its skew-symmetric portion acts as a driving force for the transmission of internal angular momentum through the fluid.

The quantum hydrodynamics of the polyatomic fluid has been formulated by employing generalized Wigner distribution functions, i.e., Fourier transforms of the density matrix. This establishes a means for examining the structure of the quantum Boltzmann equation of polyatomic gases and for characterizing the analogy between transport processes in polyatomic fluids and in chemically reacting mixtures.

[1] C. F. Curtiss, J. Chem. Phys. 24, 225 (1956).
[2] H. Grad, Comm. Pure Appl. Math. 5, 455 (1952).

PA6. Many Body Problem with Quantum Statistics. P. C. MARTIN AND J. SCHWINGER, *Harvard University.*—The real difficulty with a perturbative approach to statistical mechanics is that it probably does not converge. While the apparent dependence of the thermodynamic functions on increasing powers of the particle number, N, can be removed, the remaining expansions in the potential strength λ are generally asymptotic series for functions like λ^{λ}, $e^{1/\lambda}$ and $\log\lambda$. A quantum mechanical cluster expansion has been devised which circumvents the spurious difficulty of increasing powers of N, and appears to avoid the real one. It employs a set of coupled equations which describe the simultaneous dynamical correlations of successively larger numbers of particles. Specifically it relates the functions

$$G(r_1t_1\cdots r_nt_n;r_1't_1'\cdots r_n't_n')$$
$$=\mathrm{Tr}\{[\psi(r_1t_1)\cdots\psi(r_nt_n)\psi^{\dagger}(r_1't_1')\cdots\psi^{\dagger}(r_n't_n')]_{+}e^{-\alpha N-\beta H}\}$$
$$\times(\mathrm{Tr}\,e^{-\alpha N-\beta H})^{-1},$$

where ψ is a Heisenberg field operator, H, the Hamiltonian, N, the number operator, α and β parameters associated with the temperature and chemical potential, and ϵ a phase factor. The lowest approximation, in which two particle dynamical correlations are neglected, leads at zero temperature to the Hartree-Fock equation. The second approximation, which neglects simultaneous interactions of more than two, yields a pair of coupled equations for the one and two particle correlation functions, in which quantum statistics play an essential role. From this pair of equations the properties of the superconducting state, the electron plasma, the Bose hard sphere gas, and nuclear matter have been derived in a unified and simplified manner.

PA7. Quantum Theory of Surface Energy and Tension.*† M. NAUENBERG AND R. BROUT, *Cornell University.*—The surface energy E_s of a system of interacting particles is

$$E_s=\int_{-\infty}^{\infty}dz\left[\epsilon(z)-\epsilon_B\frac{\rho(z)}{\rho_B}\right],$$

where $\epsilon(z)$, $\rho(z)$ are the energy and particle densities along the axis normal to the surface, ϵ_B, ρ_B are the corresponding quantities in the bulk. Alternatively, one obtains an expression for the surface tension,

$$\gamma=\int_{-\infty}^{\infty}dz\Big\{2[t_s(z)-t_1(z)]$$
$$+\tfrac{1}{4}\int d\mathbf{r}\,(r^2-3r_z^2)\frac{1}{r}\frac{dv}{dr}\rho^{(2)}(z,z+\mathbf{r})\Big\}t_1(z),$$

are the components of the kinetic energy density, $\rho^{(2)}(\mathbf{r}_1\mathbf{r}_2)$ is the pair distribution function. In the ground state $\gamma=E_s$. We have applied these formulas to liquid He^4 assuming that $\rho^{(2)}=\rho(z)\rho(z+r_z)g_B(r)$. The bulk radial distribution function was obtained from x-ray data. Use of the thermodynamic data ϵ_B and $p=0$ gives t_B and checks $g_B(r)$. Further, we assume a free volume form of the kinetic energy density $t(z)=t_B[\rho(z)/\rho_B]^{5/3}$ and an exponential density fall off $\rho(z)=\rho_Be^{-z/a}$.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Abstract curtailed because two of the formulas could not be printed otherwise than as "display" formulas.

PA8. Generalized Gibbsian Ensembles. JOEL L. LEBOWITZ, *Stevens Institute of Technology.*—The general theory describing the temporal evolution of a Gibbs ensemble representing a system in contact with its surroundings is applied to several situations of interest. We consider an arbitrary physical system confined to a container fitted with two movable pistons. The outside of each piston is in contact with an ideal gas reservoir having a temperature T_i and density n_i, $i=1, 2$. The stationary Gibbs ensemble, i.e., stationary solution of the generalized Liouville equation,[1] is found when $T_1=T_2$. When in addition $n_1=n_2$, this ensemble has the form $\mu=C\exp[-(H+pV)/kT]$, where H is the Hamiltonian of the system plus piston combination, V the volume, and $p=nkT$. When $T_1\neq T_2$, the stationary ensemble, which is canonical with some average T, has been found only for the special case of a system consisting of a single piston much heavier than the particles making up the reservoirs. A more general proof than previously given for the asymptotic approach of the ensemble density to its stationary value will also be presented.

[1] J. L. Lebowitz and P. G. Bergmann, Ann. Phys. 1, 1 (1957).

PA9. Correlation Correction to the Specific Heat of a Degenerate Electron Gas.* JOHN J. QUINN AND RICHARD A. FERRELL, *University of Maryland.*—Fourier-analyzing the proper field of a moving point charge gives the ordinary Coulomb field divided by the frequency and wave-number dependent dielectric constant.[1] The self-energy results, as in quantum electrodynamics, from the action of the proper field back on the charge itself and has real and imaginary parts, corresponding to an optical model. The derivative of the total energy of an electron at the top of the Fermi sea with respect to its momentum leads to a specific heat agreeing with Gell-Mann's[2] formula. In addition the imaginary part of the self-energy is found to be $-ry(\pi/\alpha r_s)^{\frac{1}{2}}(p-1)^2/16$, indicating that the concept of a one-electron state is valid for small excitation energies but breaks down when the electron is sufficiently far removed from the Fermi surface and $(p-1)^2$ becomes appreciable. (p is the electron's momentum in units of the Fermi momentum.)

* Investigation supported by the Office of Naval Research.
[1] J. Lindhard, Kgl. Danske Mat.-fys. Medd. 28, No. 8 (1954).
[2] M. Gell-Mann, Phys. Rev. 106, 369 (1957).

PA10. Studies of Liquid Helium. IRA L. KARP, *University of Washington.*—It is shown under very general conditions that the ground state of a bound quantum system is nodeless, and the number of singly connected regions of a single sign in any higher wave function is an adiabatic invariant: a calculation of the ground-state energy of liquid helium places upper and lower bounds on it. The energy and eigenfunctions of the ground state of helium are calculated as functions of the volume per particle, assuming a Slater-Kirkwood two body potential. A critical review of the technique of calculation is presented.

PA11. Theory of Superconductivity. ARNOLD J. CANTOR AND PAUL C. MARTIN, *Harvard University.*—Bardeen, Cooper, and

Schrieffer have recently proposed an interesting theory of superconductivity. The essential feature of this theory is the existence of a coherent state whose energy differs from that of the normal individual particle Bloch states by a gap. They demonstrate the existence of this gap by a variational procedure which employs trial functions in which particles with equal and opposite momenta are paired. By means of temperature-dependent correlation functions (Green's functions) described elsewhere, their results have been rederived in a very concise form. In this derivation the chief approximations are ones which neglect the simultaneous dynamical correlation of three particles. The energy gap in the single electron energy spectrum, which reduced from the characteristic phonon energy, is determined from a pole in the two particle propagator, which appears in the equation whenever the two fermion interaction is attractive. It is further shown that the strong correlations which serve to produce the coherent state occur between particles whose center-of-mass kinetic energy is less than the very small energy associated with the gap. Thus the essentially correct character of the reduced Hamiltonian proposed by BCS is demonstrated. The investigation of the empirical parameters of the present theory by means of these techniques is presently being studied.

PA12. Fröhlich Theory of Superconductivity and the Enhancement of the Electron Specific Heat of Metals.* RICHARD A. FERRELL, *University of Maryland.*—The basic features of Fröhlich's theory of superconductivity are contained in the self-energy of an electron at the surface of the Fermi sea.[1] Lowest order Rayleigh-Schrödinger (RS) perturbation theory gives a self-energy $-GE$, where E is the unperturbed energy and G is essentially Fröhlich's dimensionless coupling constant. $G>1$ gives an instability which was interpreted by Fröhlich as resulting in superconductivity. But replacing RS by a type of Brillouin-Wigner (BW) perturbation theory, the total energy becomes $(1+G)^{-1}E$ and the instability for $G>1$ disappears. Higher terms do not upset this reinstated stability, proving Fröhlich's theory has nothing to do with superconductivity, but does give an important self-energy correction to the density of states. The above BW formula gives an increase by $1+G$, or 20%, in the electron specific heat of sodium, comparing well with the 22% enhancement found experimentally by Roberts[2] although other effects enter.

* Investigation supported by the Office of Naval Research.
[1] For further discussion and references see R. A. Ferrell, Bull. Am. Phys. Soc. Ser. II, 1, 217 (1956).
[2] L. M. Roberts, Proc. Phys. Soc. (London) **70B**, 744 (1957).

PA13. Low-Temperature Lattice Conductivity in Metals. R. W. MORSE, *Brown University.*—The lattice thermal conductivity in metals can be comparable with the electronic conductivity with impure metals or alloys, and with superconductors well below the transition temperature. Phonon-electron scattering generally is the mechanism determining the lattice conductivity. Theory has not been too successful in accounting for the observed conductivity because of uncertainty concerning the shear wave interaction with electrons, and because of the unknown effect of superconductivity on the phonon-electron interaction. Here empirical values of the phonon-electron interaction as deduced from measurements of ultrasonic attenuation will be used to calculate the lattice conductivity of tin, indium, and copper. These apply to both longitudinal and shear waves, and in the case of tin and indium, to both the normal and superconducting states. It is shown that one would expect shear waves to contribute significantly. Calculated lattice conductivities agree reasonably well with values reported in the literature for these metals. The comparison with the temperature dependence of the lattice conductivity in the superconducting states is also fairly good.

FRIDAY AFTERNOON AT 2:15

NBS, East Building

(C. G. SHULL presiding)

Invited Papers in Solid-State Physics

Q1. Effective Relaxation Parameters in Ferrimagnetic Resonance. R. K. WANGSNESS, *U. S. Naval Ordnance Laboratory.* (30 min.)

Q2. Scattering of Polarized Neutrons by Ferromagnetics and Antiferromagnetics. A. W. SAENZ, *U. S. Naval Research Laboratory.* (30 min.)

Q3. Electrical and Optical Properties of Indium Arsenide. R. M. TALLEY, *U. S. Naval Ordnance Laboratory.* (30 min.)

Q4. Magnetic and Spectroscopic Properties of Actinide-Group Compounds. J. C. EISENSTEIN, *National Bureau of Standards.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(J. H. WILLIAMS presiding)

Proton-Proton Scattering; Proton Polarization

R1. Proton-Proton Scattering at 1855 kev.* DAVID J. KNECHT, S. MESSELT, E. D. BERNERS, AND L. C. NORTHCLIFFE, *University of Wisconsin.*—The differential proton-proton scattering cross sections at 1855 kev have been measured for laboratory angles of 6° to 45°, using a modification of the chamber previously used by Worthington, McGruer, and

Findley[1] and the new Wisconsin electrostatic generator. Various sources of possible error have been investigated. Estimated experimental uncertainties are about 0.2%. Present data indicate the presence of a systematic error in the low-angle cross sections previously reported.[1] The data have been analyzed by a least-squares procedure incorporating the vacuum polarization contributions to the scattering and the relativistically correct parameters given by Durand.[2] The experimental points are fitted to about 0.1% by pure S-wave scattering alone. Without the inclusion of vacuum polarization contributions, the data cannot be fitted unless one assumes large experimental error. Measurements are being extended to other energies attainable with this generator.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] Worthington, McGruer, and Findley, Phys. Rev. **90**, 899 (1953).
[2] Loyal Durand, III, Phys. Rev. **108**, 1597 (1957).

R2. p-p Scattering at 90° in the Center-of-Mass System from 28 Mev to 68 Mev.* YUNG SU TSAI AND LAWRENCE H. JOHNSTON, *University of Minnesota*.—Accurate measurements (±2%) of the absolute differential cross section of p-p scattering at 90° in the center-of-mass system have been made. Purified hydrogen gas with 1 atmos pressure was used as a scatterer and a sodium iodide crystal was used as a detector. The preliminary results of the measurements are in Table I.

TABLE I.

Beam energy Mev	Method	$\frac{d\sigma}{d\Omega}$ at 90° c.m. mb (±2%)
67.88	A	6.18
63.28	B	6.63
57.45	B	7.44
51.02	B	8.35
45.19	B	9.44
39.6	A	11.08
36.9	C	12.06
34.2	C	13.19
31.5	C	14.57
28.5	B	16.11

Method A is by using the Minnesota LINAC beam under normal operation. Method B is by operating the linac with reduced rf and selecting the beam energy by an analyzing magnet. Method C is by using aluminum absorbers.

* Supported in part by the U. S. Atomic Energy Commission.

R3. Small Angle Polarized Proton-Proton Scattering.* J. N. PALMIERI, A. CORMACK,† N. F. RAMSEY,‡ AND RICHARD WILSON, *Harvard University*.—The angular distribution of proton-proton cross sections and polarizations has been measured at 148 Mev in the laboratory angle range of 2 to 15°. The scatterer is liquid hydrogen, contained in a two-inch-diameter cylindrical target with Mylar windows of sufficient thinness that backgrounds are in general less than 30%. The angular resolution is better than ±½°. The cross sections have been determined to ±1%, and the asymmetry to ±0.01. The cross sections indicate an interference minimum at approximately 7° in the laboratory system. The polarization appears to become negative below 4° reaching a minimum near 3°. The data will be compared with the Harwell experiments and with the predictions from recent potentials.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Tufts University.
‡ Now at NATO.

R4. Polarized Proton-Proton Scattering.* A. CORMACK,† J. N. PALMIERI, N. F. RAMSEY,‡ AND RICHARD WILSON, *Harvard University*.—The measurement of the angular distributions of proton-proton cross sections and polarizations has been completed at energies from 50 to 148 Mev. The lower energies have been obtained by utilizing liquid hydrogen and polyethelene absorbers. Measurements have been made from 15 to 55° at 148 Mev, 15 to 45° at 118 Mev and 95 Mev, and 15 to 35° at 68 Mev. Determinations have also been made at three angles only at intermediate energies, at approximately 10 Mev intervals. In all cases the angular resolution is about ±1°. Relative cross sections are determined to ±1% and asymmetries to better than ±0.01. The coefficients, obtained by the expansion of the quantity $(\epsilon d\sigma/d\Omega)/\sin\varphi\cos\varphi$ in a series of even powers of $\cos\varphi$ through the $\cos^4\varphi$ term, have been determined for the various energies. The coefficient of $\cos^2\varphi$ decreases rapidly from 148 Mev to 118 Mev, where it is close to zero.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Tufts University.
‡ Now at NATO.

R5. Polarization of 17-Mev Protons in Elastic Scattering from Nuclei.* W. BLANPIED, *Princeton University*.—Measurements have been made of the angular distribution of the polarization of protons elastically scattered from copper and magnesium at about 17 Mev laboratory energy. The familiar double scattering method was employed in which the left-right asymmetry, ϵ, following the second scattering is measured. The nucleus of interest was used as the first scatterer; the second scatterer was carbon, whose polarization is known from earlier work at this laboratory by K. Brockman.[1] NaI scintillation counters were used to detect the twice scattered protons. It was discovered that the polarizations vary more rapidly with angle than in the case of the high energy data, that the maxima and minima of the polarization occur near the diffraction minima of the differential cross section curves, and that the rapidity of the change in polarization with angle increases with increasing A. Same comparison with unpublished theoretical predictions of F. Bjorklund's will be made.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] K. Brockman, Phys. Rev. (to be published).

R6. Carbon Polarimeter for 6 Mev Proton Polarization Measurements.* ROBERT E. WARNER† AND W. PARKER ALFORD, *University of Rochester*.—Most low-energy proton polarization measurements have employed helium as a second scatterer. Calculations at 4.9 and 5.1 Mev and measurements at 5.4 Mev demonstrate that protons of these energies scattered from carbon at 45° have a polarization of about 80%. A polarimeter has been built in which protons are second scattered at 45° from a polystyrene foil and detected by scintillon crystals, 6291 phototubes, and standard electronic gear. The polarimeter has been calibrated by the second scattering of protons of known (91%) polarization obtained by scattering from C, and checked for instrumental asymmetries by the second scattering of unpolarized protons. Larger counting rates and better resolution of signal from background can be obtained than with the usual helium polarimeters. Calculated curves for $P(\theta)$ *vs* θ will be shown for protons scattered from C at several energies from 3.0 to 5.1 Mev.

* Supported by the U. S. Atomic Energy Commission and the Esso Education Foundation.
† National Science Foundation Predoctoral Fellow.

R7. Abstract withdrawn.

R8. Polarization of 5.7 Mev Protons Elastically Scattered from Nickel.* W. PARKER ALFORD AND ROBERT E. WARNER,† *University of Rochester*.—Preliminary results have been obtained for the polarization of 5.7±0.1-Mev protons elastically scattered from a nickel target at laboratory angles from 45° to 135°. Polarization was determined from the left-right asymmetry in second scattering from helium at 130° cm and 5.1-Mev laboratory energy. The largest experimental uncertainty arises from counting statistics except at 45° and only this error is quoted in the following results for the angles indicated: 45°, 0.04±0.01; 60°, 0.03±0.02; 75°, 0.04±0.05; 90°, −0.03±0.04; 105°, −0.08±0.08; 120°, −0.13±0.08; 135°, 0.04±0.06. The magnitude of these polarizations is consistent with that predicted using an optical model with a reasonable spin-orbit term in the potential. A new polarimeter is being constructed to give better counting rates and background discrimination. With it, results will be improved and extended to provide a more significant check on theoretical calculations.

* Supported by the U. S. Atomic Energy Commission and Esso Research Foundation.
† National Science Foundation Predoctoral Fellow.

R9. Elastic Scattering of 160 Mev Protons by Nuclei of Adjacent Mass.* G. GERSTEIN AND K. STRAUCH, *Harvard University*.—Elastic differential cross sections have been measured with 160 Mev protons in the angular region 9–50° for the following groups of adjacent mass elements: Na^{23}, Mg^{24}, Al^{27}; K^{39}, Ca^{40}; Fe^{54}, Ni^{58}, Ni^{60}; Ta^{181}, W^{184}, Au^{197}; Pb^{204}, Pb^{208}, Bi^{209}. These measurements were made in a way which allowed accurate comparison of the scattering cross sections within each group. The energy resolution given by the range telescope was 2.6 Mev. Results are presented in two forms: (a) as elastic differential cross sections, (b) as ratios of such cross sections within a group. The ratio presentation is a very sensitive indication of small changes in the scattering from adjacent mass nuclei. A series of WKB approximation optical model calculations using a Woods-Saxon form factor have been performed on a Univac computer. It was required that calculated absorption and total cross sections agree well with experimental neutron values. In an initial survey which omitted Coulomb potential and spin orbit coupling, best overall fit was given by the parameters $V=16$ Mev, $W=15$ Mev, $r_0=1.20$ fermi, and $a=0.57$ fermi. These values produce good agreement with experimental results for high A elements; at low A, calculated differential cross sections show deeper minima than experiment. Most of the experimental ratios are fairly well in agreement with calculations made changing only the radius, so that $\Delta r=\Delta(A^{\frac{1}{3}})$. Exceptions are noted in the ratios Fe^{54}/Ni^{58}, Ta^{181}/Au^{197}, and Pb^{204}/Pb^{208}. Possible interpretations will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Invited Paper

R10. Beta-Gamma Circular Polarization Correlation Experiments. FELIX BOEHM, *California Institute of Technology*. (30 min.)

FRIDAY AFTERNOON AT 2:15

Sheraton-Park, Burgundy Room

(K. WAY presiding)

Unstable Nuclei I

RA1. Inverse Beta Decay and the Two-Component Neutrino. R. W. KING, *Purdue University*,* AND J. F. PERKINS, *Lockheed Aircraft Corporation*.—The discrepancy between the experimental cross section for neutrino absorption by protons as determined by Cowan and Reines and that predicted by the two-component theory of the neutrino has usually been dismissed as due to the uncertainties involved in determining the spectrum of antineutrinos from fission products. From a complete summary of the known decay schemes of the fission products, we are able to establish a *firm* lower limit for the average cross section per antineutrino $\bar{\sigma}_P>7\times10^{-44}$ cm² (based on the two-component theory) which exceeds the experimental upper limit. We, furthermore, offer a "best value" for the cross section ($\bar{\sigma}_P=17\times10^{-44}$ cm²) that is several times larger than that found experimentally ($\bar{\sigma}_P=2.8\pm1\times10^{-44}$ cm²). Various improvements made on previous estimates of the antineutrino spectrum have served to widen rather than remove the discrepancies. Thus, it can be concluded that the existence of the disagreement between the two-component theory and experiment is quite real and independent of the uncertainties in the spectrum of antineutrinos.

* Assisted in part by contract with the Air Force Office of Scientific Research.

RA2. Circular Polarization of Gamma Rays Following Beta Decay.* R. M. STEFFEN, *Purdue University*.—Using differential Compton scattering on magnetized iron as polarization analyzer,[1] the degree of circular polarization and the directional distribution of the circularly polarized gamma rays following the beta decay of Co^{60} (pure Gamow-Teller transition) and of Sc^{46} (mixed Fermi and G.T. transition) has been studied in detail. It was verified that the degree of circular polarization is proportional to v/c for these allowed beta decays and that the directional distribution with respect to the beta particles is given by $W(\theta)=1\pm A\cdot(v/c)\cos\theta$.[2] The

value of A for Co^{60} was determined as $A=-0.34\pm0.02$.[1,2] Assuming that beta decay is due to the V, A interaction this yields for the coupling constants $\mathrm{Re}(-2C_AC_A'^*/|C_A|^2+|C_A'|^2)=1.02\pm0.06$. For Sc^{46} the experimental value of A is $A=+0.24\pm0.02$. Although this value is somewhat smaller than reported in reference 1, it verifies the presence of a large interference between Gamow-Teller and Fermi interaction. Assuming the maximum interference between V and A the ratio of the Fermi and the G.T. matrix element for the Sc^{46} beta decay is $|M_F|/|M_{GT}|\cong0.1$.

* Supported by the U. S. Atomic Energy Commission.
[1] F. Boehm and A. H. Wapstra, Phys. Rev. 109, 456 (1958).
[2] Alder, Stech, and Winther, Phys. Rev. 107, 728 (1957).
[3] H. Schopper, Phil. Mag. 2, 710 (1957).

RA3. Nonlinearity of the Fermi Plot of the Beta Decay of O^{14}.* D. T. GOLDMAN AND R. A. FERRELL, *University of Maryland.*—The anomalously long half-life of C^{14} is satisfactorily explained by an accidental cancellation in the allowed matrix element.[1,2] A similar explanation is used to understand the long 4.414-Mev positron decay of O^{14} to the ground state of N^{14}. The near vanishing of the allowed term indicates that forbidden terms must be considered in evaluating the complete β-decay matrix element.[2,3] Terms proportional to $\int\boldsymbol{\alpha}\times\mathbf{r}$, $\int\gamma_5\mathbf{r}$, and $\int(\boldsymbol{\sigma}\cdot\mathbf{r})\mathbf{r}$ give non-negligible contributions to the transition rate. Since these nuclear matrix elements are multiplied by the electron and neutrino momenta, the Fermi plot is nonlinear. Because of the relatively large transition energy the nonlinearity should be experimentally more easily detected than in the case of the C^{14} β decay.[3] Assuming V-A β decay coupling gives a unique Fermi plot for the O^{14} ground-state transition.

* Research supported by the U. S. Atomic Energy Commission.
[1] B. Jancovici and I. Talmi, Phys. Rev. 95, 289 (1954); J. P. Elliott, Phil. Mag. 1, 503 (1956).
[2] W. M. Visscher and R. A. Ferrell, Phys. Rev. 107, 781 (1957).
[3] B. C. Carlson and George B. Henton, Bull. Am. Phys. Soc. Ser. II, 2, 358 (1957).

RA4. Beta Spectra of Mirror Nuclei.* J. A. WELCH, JR.,† AND ROGER WALLACE, *University of California, Berkeley.*—The positron spectra and half-lives of the following mirror nuclei have been measured with a 180-degree deflection high-slip uniform-field magnetic spectrometer (see Table I).

TABLE I.

Isotope	E_{max} (Mev)	$T_{\frac{1}{2}}$ (sec)	ft (sec)
Ne^{19}	2.24±0.01	19.5 ±1.0	1900±100
Na^{25}	2.51±0.02	21.6 ±0.5	3500±250
Mg^{23}	3.09±0.01	11.9 ±0.3	4480±200
Al^{25}	3.38±0.03	7.3 ±0.3	4280±350
Si^{27}	3.85±0.02	4.33±0.02	4500±100
P^{29}	3.96±0.02	4.2 ±0.1	4740±200
S^{31}	4.39±0.03	2.58±0.06	4820±250
Cl^{33}	4.51±0.05	2.90±0.10	6000±500
A^{35}	4.93±0.05	1.84±0.10	5680±400
K^{37}	5.15±0.07	1.15±0.15	4250±500
Ca^{39}	5.43±0.06	0.89±0.05	4150±300

Variations of the end-point energies with A are explained according to the shell model by Talmi. The data definitely support jj coupling in the state of lowest seniority. Comparison of the ft values obtained with experimental nuclear magnetic moments gives the partial-coupling constants $g_F^2=1.5\times10^{-4}$ sec^{-1} and $g_{GT}^2=2.1\times10^{-4}$ sec^{-1}.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Captain, U. S. Air Force, presently stationed at Kirtland Air Force Base.

RA5. Half-Lives of Si^{27}, S^{31}, Ca^{39}, Al^{28m}, K^{38m}, Ca^{35}, P^{30}, and K^{38}.* J. E. CLINE† AND P. R. CHAGNON, *University of Michigan.*—The isotopes listed were prepared by (γ,n) or (γ,d) reactions at 85-Mev peak bremsstrahlung energy. All are positron emitters, hence thick targets were used and the positrons were detected via 2-quantum annihilation radiation. The lifetimes were measured using a digital multichannel time-delay analyzer. The data from each run were fitted by least squares to an expression containing one or two exponential decay terms and a constant background term. The results are given in Table I. The results are essentially in agreement with previous measurements or current predictions.

TABLE I.

Source	$(J^\pi,T)_i$	$(J^\pi,T)_f$	Class	Half-life
Si^{27}	$\frac{1}{2}^+,\frac{1}{2}$	$\frac{1}{2}^+,\frac{1}{2}$	Superallowed, $F+GT$	4.33 ±0.12 sec
S^{31}	$\frac{1}{2}^+,\frac{1}{2}$	$\frac{1}{2}^+,\frac{1}{2}$	Superallowed, $F+GT$	2.80 ±0.05 sec
Ca^{39}	$\frac{3}{2}^+,\frac{1}{2}$	$\frac{3}{2}^+,\frac{1}{2}$	Superallowed, $F+GT$	0.876±0.012 sec
Al^{28m}	$0^+,1$	$0^+,1$	Superallowed, pure F	6.68 ±0.12 sec
K^{38m}	$0^+,1$	$0^+,1$	Superallowed, pure F	0.951±0.007 sec
Ca^{35}	$(0^+,1)$	$0^+,1$	Superallowed, pure F	0.66 ±0.05 sec
P^{30}	$1^+,0$	$0^+,1$	Allowed, pure GT	2.62 ±0.02 min
K^{38}	$3^+,0$	$2^+,1$	Allowed, pure GT	7.67 ±0.03 min

* Work supported by a U. S. Atomic Energy Commission contract.
† Now at Phillips Petroleum Company, Idaho Falls, Idaho.

RA6. Positron Spectra of V^{46}, Mn^{50}, Co^{54}, and Cu^{58}.* JOHN H. MILLER, III, AND DAVID C. SUTTON, *Princeton University.*—The possibility of 0→0 transitions in odd-odd $N=Z$ nuclei in the $1f_{7/2}$ and $2p_{3/2}$ shells has been discussed by Moszkowski and Peaslee,[1] Stähelin,[2] Kofoed-Hansen,[3] and Gehart.[4] Martin and Breckon[5] observed positrons from V^{46}, Mn^{50}, Co^{54}, and Cu^{58} and the resulting rough ft values suggested 0→0 transitions (except in Cu^{58}). We have measured these spectra in a lens spectrometer mounted with its source in the 18-Mev proton beam of the Princeton FM cyclotron, with detectors gated off during beam pulses. Table I shows our end points together with lifetimes as summarized by Gerhart,[4] and the resulting ft values.

TABLE I.

	E_0 (Mev)	$\tau_{\frac{1}{2}}$ (sec)	ft (sec)
V^{46}	6.01±0.07	0.44±0.01	3140±200
Mn^{50}	6.56±0.09	0.28±0.02	2800±400
Co^{54}	7.27±0.10	0.18±0.01	2800±400
Cu^{58}	7.48±0.08	3.30±0.10	53 000±5000

* Supported by U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] S. A. Moszkowski and D. C. Peaslee, Phys. Rev. 93, 455 (1954).
[2] P. Stähelin, Phys. Rev. 92, 1076 (1953).
[3] O. Kofoed-Hansen, Phys. Rev. 92, 1075 (1953).
[4] J. B. Gerhart, Phys. Rev. (to be published).
[5] W. M. Martin and S. W. Breckon, Can. J. Phys. 30, 643 (1952).

RA7. Beta-Gamma Coincidence Solenoidal Spectrometer.* D. R. CARTWRIGHT, W. J. PAUL, AND J. D. KURBATOV, *The Ohio State University.*—A beta-gamma coincidence spectrometer has been developed using a magnetic type solenoidal spectrometer. Electrons are detected with a 2-in. $\phi\times\frac{1}{2}$-in. anthracene crystal transmitting the scintillations through a 2-in. $\phi\times36$-in. hollow Pyrex tube filled with toluene. Noise reduction in the 2-in. phototube is obtained by cooling with dry ice. Mu metal shielding around the phototube eliminates magnetic field interference. The gamma radiation is detected with a 2 in.×2 in. NaI(Tl) crystal which is connected to a 2 in.×36 in. light pipe filled with benzene. The two channels feed a fast-slow coincidence circuit with a tau range of 5×10^{-8} to 2×10^{-6} sec. The inner beta of Rb^{86} has been studied by coincidence procedure. The Kurie plot of the inner beta spectrum obtained in coincidence with the 1.10±0.02 Mev gamma ray gave a straight line down to 100 kev with an upper energy level of 700±10 kev. The Kurie plot of the high-energy beta spectrum was found to be of alpha shape with an upper energy level of 1.82±0.04 Mev.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

RA8. Beta Spectrum of As^{76}.* F. T. KOKOSZKA,† D. R. CARTWRIGHT, AND J. D. KURBATOV, *The Ohio State University.*—A solenoidal beta-gamma coincidence spectrometer has been used for the study of the As^{76} beta spectrum. The four previously reported beta spectra of 0.36-, 1.76-, 2.41-, and 2.97-Mev upper energy level were confirmed, and an additional fifth inner beta spectrum of ~1.20-Mev upper energy level was found. A Kurie plot of the coincidences between the beta spectra and 0.55- and 0.64-Mev gamma rays showed the presence of four inner beta spectra, the additional being the 1.20-Mev upper energy level. A Kurie coincidence plot of beta spectra with the 1.20- and 1.40-Mev gamma rays produced 1.76- and about 1.20-Mev upper energy level beta spectra with the 2.41- and 0.36-Mev upper energy level beta spectra now eliminated. Coincidences between the 2.05-Mev gamma ray and the lowest energy beta spectrum established the ~0.36-Mev upper energy level. Coincidences of the gamma rays emitted and the scheme of disintegration will be presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Captain, U. S. Air Force, on tour of duty at The Ohio State University.

RA9. Nuclear Spectra of Rb^{90}. N. R. JOHNSON, G. D O'KELLEY, AND E. EICHLER, *Oak Ridge National Laboratory.** —Rb^{90} has been prepared by electrostatic collection of rubidium ions resulting from Kr^{90} decay. The krypton activity was produced from the neutron-induced fission of U^{235} and was separated from the other gaseous fission products by chromatographic techniques. Both single-crystal and coincidence gamma-ray spectra of this 2.7-minute activity have been studied by use of 3-inch×3-inch NaI crystal spectrometers. The spectrum obtained with the single-crystal arrangement showed gamma rays with energies of 0.52, 0.62, 0.85, 1.08, 1.4, 1.7, 1.9, 2.2, 2.6, 2.8, 3.4, 4.1, 4.4, and 5.3 Mev. Coincident with the intense 0.85-Mev photopeak were gamma rays at 0.39, 0.53, 0.87, 1.08, 1.3, 1.4, and 1.7 Mev, as well as indications for higher energy components. With an anthracene crystal detector the maximum energy beta-ray group was found at about 6 Mev. Results of beta-gamma coincidence measurements will also be discussed.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

RA10. Decay of $_{50}Sn^{113}$ (112-day) and $_{50}Sn^{123}$ (130-day).* H. A. GRENCH, S. B. BURSON, AND L. C. SCHMID, *Argonne National Laboratory.*—Sn^{113}.—The principal mode of decay is via orbital-electron capture to a 395-kev isomeric state (1.7 hours) in In^{113}. An additional capture branch (~2%) has been observed which decays to an excited state at 650 kev. This state decays promptly (less than 4×10^{-8} second) to the 395-kev level. The 255-kev transition exhibits a $K/(L+M)$ ratio of ~4 and an α_k of approximately 0.065. These results are consistent with a character of $M1$ or $E2$. The spin of the ground state of In^{113} is probably $9/2^+$, that of the 395-kev level is $1/2^-$; a spin of either 1/2 or 3/2 with negative parity for the 650-kev state is compatible with the experimental observations. Sn^{123}.—A weak gamma transition of 1.08 Mev is found to be associated with the decay of Sn^{123}. Its assignment to this activity is confirmed by a study of neutron-activated tin isotopes and by chemical methods. Coincidences are observed between the 1.08-Mev gamma ray and beta rays with an end-point energy of about 0.38 Mev. The apparent energy sum is consistent with the observed end point of 1.42 Mev for the principal beta-ray branch.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

RA11. Decay Schemes for Neutron-Rich Isotopes of Pd and Ag. C. D. CORYELL, U. SCHINDEWOLF, AND J. M. ALEXANDER,* *M.I.T.*—Fast chemical separations of palladium and silver from deuteron-produced uranium fission products, followed by discriminatory time and β and γ radiation analyses and characterization of Cd descendants of these, provide the following decay patterns (new species in bold face): 1.4-min Pd^{113} ($5/2+$ or $1/2+$)→**1.2-min Ag^{113m}** ($7/2+$) and 5.3-hr Ag^{113} ($1/2-$); **2.4-min Pd^{114}→~5-sec Ag^{114}** ($1+$); **45-sec Pd^{115}** ($1/2+$)→**~20-sec Ag^{115m}** ($1/2-$, 28% β^1) and 21.1-in Ag^{115} ($7/2+$); 2.5-min Ag^{116}; and **1.1-min Ag^{117}→** (Cd,In)^{117} isomeric pairs.[2] The spin and energy data for odd-A Ag isomers provide interesting correlations, with probable discontinuity at $N=64$. Postulating reasonable fission yields,[3] Pd^{116} and Pd^{117} have half-periods <30 sec. The $11/2-$ state for odd-A Pd species[4] was not observed in this mass region.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] A. C. Wahl and N. A. Bonner, Phys. Rev. **85**, 570 (1952).
[2] Coryell, Lévêque, and Richter, Phys. Rev. **89**, 903 (1953); McGinnis, *ibid.*, **94**, 371 (1954).
[3] J. M. Alexander and C. D. Coryell, Phys. Rev. **108**, 1274 (1957).
[4] U. Schindewolf, Phys. Rev. **109**, 1280 (1958).

RA12. Decay of Long-Lived Sn^{126}.* CHARLES J. ORTH AND B. J. DROPESKY, *Los Alamos Scientific Laboratory.*—A new long-lived tin activity (Sn^{126}) has been found in a radiochemically purified tin fraction removed from $\sim2\times10^{18}$ fissions of ~9-year old Water Boiler reactor "soup." Scintillation spectrometer studies of the radiations from this sample showed the presence of 26-, ~37-, ~67-, 92-, 405-, and 670-kev photons and at least two beta groups having end points of 0.42 and ~1.9 Mev. The relatively intense 0.42-Mev β radiation and coincident photons of energies 26 and ~37 kev are presumed to be due to long-lived Sn^{126m},[1] heretofore unknown as a fission product. The gamma rays at 405 and 670 kev suggested the presence of 18.8-min Sb^{126};[2,3] a rapid separation of antimony from the tin sample confirmed the presence of a 19-min activity having these gamma rays and a beta spectrum having at least two groups of end-point energies ~0.5 and 1.9 Mev. A longer lived activity (t 1/2~14 days) in this antimony fraction was found to emit ~170-, 405-, and 670-kev gamma rays and is presumed to be a second isomer of Sb^{126}.[3] The half-life of Sn^{126} is estimated to be $\sim10^5$ yr. Work is continued on these activities.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Nelson, Ketelle, and Boyd, Oak Ridge National Laboratory Report, ORNL-828, November, 1950 (unpublished).
[2] Franz, Radicella, and Rodriguez, Z. Naturforsch. **11a**, 1038 (1956).
[3] The principal antimony activities produced by the (n,p) reaction on enriched Te^{126} decayed with half-lives of 11.5 min, 23 min, and ~11.5 days (personal communication with J. W. Barnes of this Laboratory).

FRIDAY EVENING AT 7:00

Shoreham, Terrace Room

(J. W. BEAMS presiding)

Banquet of the American Physical Society

After-dinner speakers to be announced.

SATURDAY MORNING AT 9:30

Sheraton-Park, Burgundy Room

(R. W. HAYWARD presiding)

Unstable Nuclei II

S1. Radiations from Ba^{129}.* W. HENKES, *Brookhaven National Laboratory* (introduced by G. Friedlander).—Barium-129 was produced from enriched Ba^{130} by irradiation with fast neutrons from the 60-in. cyclotron of Brookhaven National Laboratory and chemically purified. The radiations were studied with single-crystal and coincidence scintillation spectrometers. The spectrum obtained with a 3×3 in. NaI crystal showed γ rays with energies of 0.127, 0.182, 0.210, and 1.45 Mev. Triple coincidence measurements showed the 0.127- and 0.210-Mev peaks to be in coincidence with positron annihilation radiation; however, they are not in coincidence with each other. The 1.45- and 0.128-Mev lines were found to be in coincidence with each other. Relative intensities of the γ lines will be given. The half-life was determined from the positron decay and the decay of the 1.45-Mev line to be 2.45±0.05 hr to be compared with the previously reported value of 1.8 hr[1] and 2.0 hr.[2]

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. C. Thomas, Jr., and E. O. Wiig, J. Am. Chem. Soc. **72**, 2818 (1950).
[2] R. W. Fink and D. H. Templeton, J. Am. Chem. Soc. **72**, 2818 (1950).

S2. Decay of Ba^{133}.* M. G. STEWART, D. C. LU, AND F. M. CLIKEMAN, *Iowa State College*.—Gamma rays following electron capture of Ba^{133} were studied with a coincidence scintillation spectrometer. Energies of 382, 357, 301, 276, 220, 162, 81, 81, and 56 kev were observed. The proposed decay scheme for Cs^{133} involves the following energy levels and spin assignments: ground state ($\frac{7}{2}+$),[1] 81 kev ($\frac{5}{2}+$), 162 kev ($\frac{3}{2}+$ or $\frac{5}{2}+$) 382 ($\frac{3}{2}+$) and 438 ($\frac{1}{2}+$). The directional correlation measurement of the 357–81 kev cascade gives the following angular distribution coefficients: $A_2/A_0=0.031\pm0.006$ and $A_4/A_0=-0.006\pm0.010$; indicating a mixture for the 81-kev transition with $\delta=-0.139\pm0.007$, where δ is the ratio of the $E2$ to the $M1$ matrix elements. The half-life of the 81-kev state was measured to be 6.0×10^{-9} sec in agreement with the measurements by Graham and Bell[2] in their study of Xe^{133} decay. For this state the $E2$ transition probability is enhanced by a factor of 10 and the $M1$ transition probability is retarded by a factor of 775, compared to single particle transitions, in agreement with a $g_{\frac{7}{2}}$ assignment for the ground state and $d_{\frac{5}{2}}$ for the 81-kev state.

* This work was supported by the U. S. Atomic Energy Commission.
[1] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).
[2] Graham and Bell, Can. J. Phys. **31**, 377 (1953).

S3. L Auger and Coster-Kronig Transition Yields for Cs^{137}–Ba^{137}.* A. O. BURFORD† AND S. K. HAYNES,‡ *Vanderbilt University*.—The L Auger spectrum of $Cs^{137}-Ba^{137}$ which was obtained in experiments previously described[1,2] has been analyzed. The following values are consistent with the experimental results and values for L subshell fluorescence yields available from existing literature: $a_1=0.28\pm0.06$; $0.52\pm0.14\leq a_2\leq0.74\pm0.16$; $a_3=0.95\pm0.01$; $f_{12}+f_{13}=0.66\pm0.07$; $0.16\pm0.16\leq f_{23}\leq0.38\pm0.14$; where $a_i=L_i$ subshell Auger yield; f_{ij}=probability for transfer of a vacancy from L_i subshell to L_j subshell.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Lockheed Aircraft Corporation.
‡ Now at Michigan State University.
[1] Burford, Thomas, Lafferty, and Haynes, Bull. Am. Phys. Soc. Ser. II, **1**, 260 (1956).
[2] S. K. Haynes and A. O. Burford, Bull. Am. Phys. Soc. Ser. II, **1**, 260 (1956).

S4. Evidence for Axial Vector Interaction in the 0− to 0+ β Decay of Pr^{144}. R. L. GRAHAM, J. S. GEIGER, AND T. A. EASTWOOD, *Atomic Energy of Canada Limited*.—A detailed study of the disintegration scheme of Pr^{144} has been carried out using lens spectrometers, scintillation spectrometers, and fast coincidence techniques. The 2293-kev β component (1.3%) studied in coincidence with γ 691 has a predominantly first forbidden unique shape and a strongly anisotropic directional correlation. The results indicate a probable spin sequence $0-(\beta)2+(\gamma)0+$, but the accuracy is not sufficient to completely exclude a 1− assignment for Pr^{144}. The β 803 component (1.0%) observed in coincidence with γ 2181 has an allowed shape and an isotropic directional correlation. The shape of the total β spectrum was studied in a double lens spectrometer having good antiscattering properties using sources of Ce^{144} oxide sublimed onto 200 $\mu g/cm^2$ Al leaf. Subtraction of a 1.3% unique (B_{ij}) shape 2293-kev component and a 1.0% allowed shape 803-kev component yields the ground-state β spectrum. Analyses were made using the functions of Zerianova[1] which assume uniform charge distribution with $r=1.2\,A^{\frac{1}{3}}\,10^{-13}$ cm as well as those of Rose $r=1.41\,A^{\frac{1}{3}}\,10^{-13}$ cm. The shape is essentially allowed and is consistent with pure axial vector interaction (0− to 0+). No acceptable fit (for 0− to 0+) is possible with tensor, pseudoscalar or any interfering TP admixture using Rose's theory.[2]

[1] L. N. Zerianova, Izvest. Akad. Nauk S.S.S.R. **20**, 1399 (1956).
[2] M. E. Rose and R. K. Osborn, Phys. Rev. **93**, 1324 (1954).

S5. Shape of Pr^{144} Beta Spectrum.* J. H. HAMILTON AND L. M. LANGER, *Indiana University*.—If the ground state of Pr^{144} is 0−, the transition to the 0+ ground state of Nd^{144} might exhibit possible manifestations of the influence of the pseudoscalar interaction. A precise, high-resolution, magnetic spectrometer measurement was made with 10^5 to 10^6 counts at each point. In the interval 2.3 to 2.8 Mev, the shape factor is constant to better than 1%. A least square F–K plot yields an end point of 3.01±0.02 Mev. There is, thus, no necessity to include the pseudoscalar interaction. Our measurements disagree with those of Laubitz,[1] who reported a 10% variation in the shape factor over this same energy region. In spite of the excellent statistics and reproducibility of the data, it is unfortunately not possible to establish definitively whether the first inner spectrum has the "unique" shape require for a 0− to 2+ transition. This uncertainty arises from the inherent errors introduced by the subtraction method of resolving a weak inner group and from the fact the extrapolation of the ground-state spectrum as an exact statistical shape may not be completely justified at low energies.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by a grant from the Research Corporation.
[1] M. J. Laubitz, Proc. Phys. Soc. (London) **69A**, 789 (1956).

S6. Decay of Nd^{151}.* L. C. SCHMID AND S. B. BURSON, *Argonne National Laboratory*.—$_{60}Nd^{151}$ (12-min) was produced by neutron irradiation of enriched neodymium oxide (94.8% Nd^{150}) in the Argonne reactor (CP5). This decay is characterized by β^- emission to several excited states in $_{61}Pm^{151}$. Absorption measurements in aluminum indicate three beta components. These have end-point energies of 1.24, 1.79, and 2.04 Mev. Tentatively, nine excited states are deduced from a study of the radiations using the Argonne 256-channel

scintillation spectrometer. These have energies of 0.117, 0.257, 0.434, 0.538, 0.855, 1.12, 1.28, 1.87, and 2.17 Mev. Nineteen gamma transitions have been observed. These transitions have energies of 0.085, 0.110, 0.117, 0.140, 0.176, 0.257, 0.300, 0.318, 0.403, 0.421, 0.540, 0.595, 0.682, 0.735, 1.00, 1.12, 1.17, 1.75, and 2.17 Mev. The transitions are fitted into a consistent decay scheme by means of coincidence measurements.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

S7. Decay of Gd^{150}.* S. S. MALIK,† NARENDA NATH,‡ AND C. E. MANDEVILLE, *Bartol Research Foundation*.—The decay of Gd^{150} has been studied with the aid of a thin magnetic lens beta-ray spectrometer and coincident scintillation spectrometers. Two principal beta-ray groups, with the end-point energies of 580±20, and 940±20 kev, have been resolved, the higher energy group being the more intense. Six gamma rays of energy 56, 80, 136, 225, 300, and 365 kev have been observed to decay with the half-life of Gd^{150}, revealing energy levels in the residual nucleus, Tb^{150}, at 56, 136, and 365 kev. Investigations are being carried on to obtain further information as to the nature of the gamma-ray transitions, etc.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Permanent address: M. Nagar (U.P.), India.
‡ Permanent address: Delhi, India.

S8. States in Ho^{165} Formed in the β^- Decay by Dy^{165} (2.3-hr).* JOHN V. KANE, RUDOLPH SHER, AND EUGENE V. WEINSTOCK, *Brookhaven National Laboratory*.—The gamma-ray spectrum of states in Ho^{165} following the decay of 2.3-hr Dy^{165} has been investigated using NaI(Tl) scintillation spectrometers in prompt and delayed coincidence. Singles spectra reveal gamma lines of the following energies and approximate intensities: 1068±4 kev (1.4); 1000±6(1.0); 710±4(73); 630±5(111); 553±5(50); 358±4(124); 278±4(62); and 95 kev (560). Coincidence measurements show that the 279 kev and 710 kev are in prompt coincidence; an upper limit for the lifetime of the intermediate state of this cascade may be set at 10^{-7} sec. The 630–360 kev cascade is found to exhibit delayed coincidences; the half-life of the 360-kev state is found to be $1.65\pm0.20\times10^{-6}$ second. A decay scheme based on these data and those of previous investigations[1] will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Jordan, Cork, and Burson, Phys. Rev. 92, 1218 (1953).

S9. Decay of Platinium-188.* P. S. FISHER AND R. A. NAUMANN, *Princeton University*.—Sources of ten-day platinum-188 have been prepared by 50-Mev proton irradiation of iridium in the Nevis synchrocyclotron. The radiations accompanying the decay of Pt^{188}-Ir^{188} equilibrium mixtures and sources of pure Pt^{188} and Ir^{188} have been observed, using scintillation coincidence and conversion electron spectroscopy. Prompt coincidences ($2\tau=2\times10^{-9}$ sec) have been found between the 190-kev and 270-kev transitions in Ir^{188} as well as 190 kev $-K$ x-ray coincidences. The group of transitions at 400 kev in Ir^{188} are in coincidence with L x-rays ($2\tau=2\times10^{-9}$ sec). Levels in Os^{188} excited from Ir^{188} decay have been observed up to 2 Mev. Conversion electron spectroscopy revealed L conversion electrons from a 55-kev transition in Ir^{188}, as well as K conversion electrons at 112 and 119 kev, suggesting that the 190-kev transition in Ir^{188} is complex. In addition K and L conversion electrons for the well-known 155-kev ($2+\rightarrow0+$) transition in Os^{188} were noted. The similarity in intensity of the transitions excited by Re^{188} β^- decay and Ir^{188} K capture suggests a low spin for 41-hour Ir^{188}.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

S10. Angular Correlation Measurements in Tl^{201}.* B. I. DEUTCH AND N. GOLDBERG, *University of Pennsylvania*.—Angular correlation measurements have been made on the 400-kev and 280-kev transitions following electron capture from 52-hour Pb^{203}. The source was produced by the $Tl^{203}(d,2n)Pb^{203}$ reaction and was separated carrier-free by an anion exchange resin column. The following directional correlations were measured: gamma-gamma, K conversion electron-gamma, and gamma-K conversion electron. In measurements involving conversion electrons, sources were prepared by vacuum evaporation of $PbCl_2$ onto 200 $\mu g/cm^2$ Al foil. The conversion electrons were detected in a thin-lens beta spectrometer and the γ rays were detected with a NaI crystal mounted on a photomultiplier. The angular distribution of all measurements were of the form $W(\theta)=1+A_2P_2(\cos\theta)$. The following results were obtained: For the $400\gamma-280$ Ke^- correlation $A_2=-0.051\pm0.010$, for the $280\gamma-400$ Ke^- correlation $A_2=-0.036\pm0.010$, and for the $400\gamma-280\gamma$ correlation $A_2=-0.140\pm0.010$. The ratio of the anisotropy in a solid Pb source to the anisotropy in a molten Pb source was 1.14±0.15 showing that any attenuation was small. The 400-kev level K conversion coefficient is 0.142 ± 0.020, using the known branching ratios and conversion coefficients of the 280-kev level.

* This research was supported in part by a grant from the National Science Foundation and the Office of Ordinance Research, U. S. Army.

S11. Isomeric Level in Pb^{216} Formed by the Decay of Bi^{216}.* S. H. VEGORS, JR., AND R. L. HEATH, *Phillips Petroleum Company*.—All of the odd isotopes of lead, with the exception of Pb^{215}, have well-established isomeric levels. To the present time there has been no evidence for an isomeric level in Pb^{216}. In the course of an investigation of the electron capture decay of Bi^{216} it was noted that one of the major transitions, the 987-kev gamma ray, was not in prompt coincidence with the electron capture x-rays. Further investigation using a NaI well crystal and delayed coincidence techniques indicates that the 987-kev level in Pb^{216} is isomeric. Its half-life was measured to be 4.7±1.5 milliseconds. The experimental evidence leading to the conclusion that the 987-kev level is isomeric, together with some of the implications of this isomerism in the decay scheme of Bi^{216} will be discussed. Additional information on the decay of Bi^{216} will be presented. Sources were prepared from cyclotron-irradiated lead, using the reaction $Pb^{204}(p,2n)Bi^{216}$. To minimize interference from Bi^{207}, radiogenic lead (≈85% Pb^{206}) obtained from uranium ore was used as a target.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:15

Sheraton-Park, Continental Room

(G. M. TEMMER presiding)

Nuclear Reactions III

T1. Angular Distribution of $Al^{27}(n,p)Mg^{27}$ Groups.* O. E. OVERSETH, JR.,† AND R. A. PECK, JR., *Brown University*.—In recent studies[1,2] of the title reaction, angular distribution information has been limited to anisotropy ratios for gross portions of the spectrum, although known levels of Mg^{27} are resolved in this spectrum,[3] for some of which l values are also

known. Angular distributions for specific transitions are thus possible, and desirable for comparison with direct interaction models.[3] Distributions have been obtained for four transitions covering the first 5 Mev of excitation, using 14.1-Mev neutrons and photographic detection of protons over all angles between 10° and 70°. Elimination of emulsion recoils and other proton background leaves about 100–200 well-screened protons for each transition. These are sufficient to provide distinct distributions with definite peaks in the angular range studied; e.g., transitions to ground state and 1-Mev level peak near 30° and 40°, respectively. The distributions seem compatible with direct interaction forms, with reasonable choice of radius and l assignments consistent with the shell model.

* Supported in part by the U. S. Atomic Energy Commission.
† Ohio Oil Fellow, 1956–1957; now at Princeton University.
[1] D. L. Allan, Proc. Phys. Soc. (London) **A68**, 925 (1955); **70**, 195 (1957); L. Colli and U. Facchini, Nuovo cimento (10) **4**, 671 (1956); G. Brown *et al.*, Phil. Mag. (June, 1957).
[2] R. K. Haling *et al.*, Phys. Rev. **106**, 971 (1957).
[3] S. T. Butler and O. H. Hittmair, *Nuclear Stripping Reactions* (John Wiley and Sons, Inc., New York, 1957), and bibliography.

T2. Cross Sections for $Si^{28}(n,p)Al^{28}$ and $Cr^{52}(n,p)V^{52}$. W. E. THOMPSON, J. M. FERGUSON, AND B. D. KERN.* *U. S. Naval Radiological Defense Laboratory.*—Silicon and chromium were bombarded with neutrons produced by the $T(d,n)He^4$ reaction with 1.5-Mev deuterons. The relative cross sections for the (n,p) reactions at different energies were obtained by measuring the gamma-ray activity in the resulting Al^{28} and V^{52} with a 3 in.×3 in. NaI(Tl) well crystal and a 100-channel pulse-height analyzer. The cross sections relative to the cross section at 14.5 Mev for $Si^{28}(n,p)Al^{28}$ are: at 12.3 Mev, 1.27; 13 Mev, 1.17; 13.7 Mev, 1.26; 15 Mev, 0.963; 16 Mev, 0.83; 17 Mev, 0.69. For $Cr^{52}(n,p)V^{52}$ the relative cross sections are: at 12.3 Mev, 0.77; 13 Mev, 0.90; 14 Mev, 1.03; 15 Mev, 0.94; 16 Mev, 0.80; 17 Mev, 0.56, 292±45 mb was obtained for the $Si^{28}(n,p)Al^{28}$ cross section at 14.5 Mev based on the cross section of 26±4 mb for $Li^6(n,t)He^4$.[1] Similarly, 87±13 mb was obtained for the $Cr^{52}(n,p)V^{52}$ cross section at 14.5 Mev. These values are to be compared with earlier reported values of 220±44 mb and 77.7±11 mb.[2]

* On leave of absence from the University of Kentucky.
[1] F. L. Ribe, Phys. Rev. **103**, 741 (1956).
[2] E. B. Paul and R. I. Clark, Can. J. Phys. **31**, 267 (1953).

T3. Lifetime of the First Excited State of K^{40}.* R. E. HOLLAND AND F. J. LYNCH, *Argonne National Laboratory.*—The excitation energy and lifetime of the first excited state of K^{40} have been measured. The Argonne 4-Mev electrostatic accelerator was used to produce this state through the reaction $A^{40}(p,n)K^{40}$ in a gas target and the photopeak produced by the gamma ray was observed in a NaI scintillation counter. This peak was compared to the photopeaks produced by the K x-rays from tin, tellurium, and cesium to obtain an excitation energy for this state of 28±1 kev. The mean lifetime of the state was measured by a pulsed beam technique[1] similar to that previously used to measure the neutron spectra by time-of-flight from the same reaction. A "prompt" time spectrum was obtained using the K x-rays of tin. An analysis of the exponential tail of the time spectrum resulting from the K^{40} gamma ray gave a mean lifetime for this state of 5.8±0.5 mμsec. These data are consistent with a magnetic dipole transition to the ground state of K^{40}, for which the single-particle estimate of the mean lifetime is 1.6 mμsec.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Holland, Lynch, and Tsukada, Bull. Am. Phys. Soc. Ser. II, **3**, 103 (1958).

T4. Energy Levels of K^{41}.* H. A. ENGE, W. H. MOORE, AND J. W. KELLEY, *M.I.T.*—A target of enriched $K^{41}I$ on a Formvar backing has been bombarded with 6.5-Mev protons from the MIT-ONR generator. The energy spectrum of protons elastically and inelastically scattered through an angle of 90 degrees has been studied by aid of the broad-range spectrograph. The data indicate levels in K^{41} at approximately 0.99, 1.30, 1.57, 1.59, 1.69, 1.71, 2.15, and 2.17 Mev. Whether a level at 0.72 Mev[1] exists or not could not be determined from our present data because the region of interest in the proton spectrum was obscured by the intense peak of protons elastically scattered from C^{12}.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).

T5. Neutron Groups from the $Ca^{48}(p,n)Sc^{48}$ Reactions.* A. J. ELWYN, G. N. GLASOE, H. H. LANDON, AND S. OLEKSA, *Brookhaven National Laboratory.*—The energy level structure in the vicinity of the ground state of Sc^{48} has been observed utilizing the $Ca^{48}(pn)Sc^{48}$ reaction. Protons of 3 Mev from the BNL 18-inch cyclotron were used to bombard a thin target, enriched in Ca^{48}.[1] Five neutron groups have been separated according to neutron time of flight by means of a technique previously reported.[2] The highest energy groups are of relatively very low intensity. The following are the energies of the neutron groups definitely observed: 2.23, 2.12, 1.78, 1.28, and 1.02 Mev. Further work is being done to establish the Q values. Careful investigation of the neutron spectrum in the region of the highest energy neutron groups is underway to limit the possibility of the existence of even lower intensity groups than have been statistically established already.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] The sample of Ca^{48}, enriched to about 80%, was obtained from E. der Mateosian and M. Goldhaber.
[2] Landon, Elwyn, and Glasoe, Bull. Am. Phys. Soc. Ser. II, **2**, 233 (1957).

T6. $Ni^{58}(p,\alpha)Co^{55}$ and $Ni^{58}(p,2\alpha)$ Excitation Functions to 22 Mev. JOHN L. NEED AND WILLIAM H. WEBB,* *Oak Ridge National Laboratory.*—In a continuation of the comparison of nitrogen- and proton-induced nuclear reactions[1,2] measurements were made of the excitation function for the (p,α) and $(p,2\alpha)$ reactions on Ni^{58}. The compound nucleus is Co^{59} excited to a maximum of 26 Mev. Stacked nickel foils were bombarded in the external beam of the ORNL 86-inch cyclotron. They were chemically processed, and the fractions were counted under end-window Geiger counters. The identification of the products was made by half-life in each fraction. The apparent (p,α) threshold is 6 Mev above the energetic threshold. The $(p,2\alpha)$ reaction is very small at these energies, being only one for two thousand of the (p,α) at 22 Mev. Comparison will be made to the $K^{39}(N^{14},\alpha)Cr^{49}$ and $K^{39}(N^{14},2\alpha)Ti^{44}$ results[2] and the cross sections will be presented.

* Research Participant from University of Missouri, School of Mines and Metallurgy.
[1] Cohen, Reynolds, and Zucker, Phys. Rev. **96**, 1617 (1954).
[2] Halbert, Pinajian, and Zucker, Bull. Am. Phys. Soc. Ser. II, **3**, 39 (1958).

T7. Study of the $Y^{89}(n,\gamma)Y^{90}$ Reaction. G. A. BARTHOLOMEW, P. J. CAMPION, J. W. KNOWLES, AND G. MANNING, *Chalk River Laboratories.*—The capture γ rays following thermal neutron bombardment of a target of very pure Y_2O_3[1] have been studied between 140 kev and 3 Mev with a flat crystal diffraction spectrometer and between 3 and 7.6 Mev with a pair spectrometer. The spectrum was found to be remarkably simple compared to those of neighboring odd-odd product nuclei, an effect probably associated with the shell structure of Y^{90} (protons, closed $f_{5/2}$ subshell plus one $p_{1/2}$ proton; neutrons, closed 50-shell plus one $d_{5/2}$ neutron). Among some seventeen γ rays detected the most prominant are at 6.072±0.009, 0.7767±0.0002, 0.5747±0.0003, and 0.2024±0.0003 Mev. The last three of these radiations were found to be in coincidence with the first in a separate experi-

ment using NaI crystal detectors. The γ rays are consistent with a neutron binding energy for Y^{90} of 6.849 ± 0.009 Mev and levels in that nucleus at 0.2024 ± 0.0003, 0.245 ± 0.002, 0.7767 ± 0.0002, 1.215 ± 0.002, and 2.80 ± 0.07 Mev.

[1] We are indebted to the U. S. Atomic Energy Commission for providing this material.

T8. Gross Structure in Proton Spectra from (d,p) Reactions.* J. P. SCHIFFER AND L. L. LEE, JR., *Argonne National Laboratory.*—The yield of protons has been observed from the (d,p) reaction on Ti, V, Cr, Mn, Fe, Co, Ni, Cu, and Zn nuclei. Observations of the emitted protons were made at 0°, 45°, 90°, and 135° for incident deuteron energies between 3 and 4 Mev. The energy spectrum of protons was measured with a CsI scintillation spectrometer of about 10% resolution. The proton energies observed correspond to states in the final nuclei from the ground state to excitations of about 4 Mev. With the experimental resolution considerably larger than the spacing of individual levels the spectrum of the emitted protons showed systematic gross structure. Similar effects were observed for adjacent odd-odd and even-odd final nuclei. Possible interpretations of this effect will be discussed.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

T9. 23-Mev Proton-Induced (p,p'), (p,d), and (p,t) Reactions. BERNARD L. COHEN AND ALLEN G. RUBIN, *Oak Ridge National Laboratory.*—Measurements were made of energy distributions of protons, deuterons, and tritons from 23-Mev proton-induced (p,p'), (p,d), and (p,t) reactions in various elements through the periodic table and at several angles relative to the incident beam. The energies are measured with a CsI (Tl) scintillation crystal, and particle identification is accomplished by combining this with a $-dE/dx$ pulse from a thin proportional counter in front of it. The proton energy distributions may be qualitatively explained as Maxwell distributions multiplied by Coulomb barrier penetration factors, except that there is an excess of low-energy particles. Both the deuteron and triton distributions are peaked near their maximum energies. Their falloffs with decreasing energy are quite rapid, and cannot be explained by Coulomb barrier effects; however, they can be simply explained by parentage considerations if (p,d) and (p,t) reactions are assumed to proceed very predominantly by neutron pickup. Angular distributions of all praticles are peaked in the forward direction. Typical cross sections for (p,p') and (p,d) reactions are 300 mb and 60 mb, respectively; they vary slowly through the periodic table. Cross sections for (p,t) reactions increase with increasing atomic number; for heavier elements, they are typically $\approx$15 mb.

T10. Gross Structure in (d,p) Spectra.* R. A. PECK, JR., *Brown University,* AND J. LOWE, *University of Birmingham, England.*—Studied with "poor" resolution, (p,p'), (p,d), (p,α), (n,p), and (d,p) spectra exhibit gross structure[1] reminiscent of neutron giant resonances. Whether this reflects vestigial single-particle characteristics in the strength function may be tested by comparison of angular distributions of the maxima with a shell model l values; the (d,p) reaction is especially suitable, involving a unique set of levels (bound neutrons). A (d,p) gross structure study has been made for Sn^{120} and In^{115} targets at 20 Mev, with a two-crystal detector and gated kicksorter. Data cover 6 Mev of excitation and eighteen angles from 13° to 155°. From Sn^{120} persistent gross groups are found, with widths and separations of order 1–2 Mev. All have essentially the same angular distribution, sharply peaked at or forward of 20° and falling almost monotonically (half forward intensity around 35°). The insensitivity of angular distribution to Q argues against direct correlation with the shell model. In this characteristic and in quantitative features of shape the distributions strongly resemble (p,p') and (p,d) and differ markedly from the isotropy found for (p,n) reactions.[2]

* Work performed at Birmingham; support by the John Simon Guggenheim Foundation is gratefully acknowledged by one of us (R.A.P.).

[1] B. L. Cohen, Phys. Rev. **105**, 1549 (1957); **106**, 995 (1957); Bull. Am. Phys. Soc. Ser. II, **3**, 58, 59 (1958); R. A. Peck, Jr., Phys. Rev. **106**, 965 (1957); L. Colli and S. Micheletti, Nuovo cimento **6**, 1001 (1957).

[2] J. P. Schiffer and L. L. Lee, Jr., Bull. Am. Phys. Soc. Ser. II, **3**, 37 (1958).

T11. Inelastic Scattering of 30-Mev Alpha Particles. D. R. SWEETMAN* AND N. S. WALL, *M.I.T.*—The inelastic scattering of 30-Mev alpha particles produced by the M.I.T. cyclotron has been studied using a thin proportional counter, biased to count only particles with a specific ionization equal to or greater than elastically scattered alpha particles, in conjunction with a CsI scintillation spectrometer. The energy resolution of this system was such that the full width at half-maximum of the elastically scattered alpha particles was about 4%. So far, the scattering corresponding to excitation energies of up to about 15 Mev has been studied in Ti, Ni, Fe, Cu, Se, Zr, Pd, and Au. In most of these elements at least one group of inelastically scattered particles corresponding to relatively low ($\sim$4 Mev) excitation energy was observed. In addition, in several cases, other structure has been seen. Preliminary angular distributions have been measured of the alpha particles corresponding to some of the groups observed in the energy spectra. These angular distributions show pronounced forward peaking indicating a direct excitation process.

* Commonwealth Fund Fellow.

T12. Nuclear Level Densities from (α,α'), (α,p), and (d,α) Reactions.* GEORGE MERKEL, *University of California, Berkeley.*—The following have been obtained: (1) the energy distributions of alpha particles and (or) protons emitted at 135 deg when Al, Ni, Cu, Ag, Ta, and Pb are bombarded with 48-Mev alpha particles; (2) the energy distributions of alpha particles emitted at 135 deg when Al, Ni, and Cu are bombarded with 24-Mev deuterons; and (3) a number of angular distributions for various residual nuclei excitations in some of the above (α,α'), (α,p), and (d,α) reactions. When the statistical theory of nuclear reactions is used to obtain the densities of energy levels from the (α,α') and (α,p) data at 135 deg, the variations of the densities are described quite well by expressions of the form $(\text{const})E^{-5/4}\exp(2aE)^{\frac{1}{2}}$ for $4\lesssim E\lesssim 23$ Mev, where E is the excitation energy of the residual nucleus. [The interpretation of the (α,α') data for $E\lesssim$23-Mev and of the (d,α) data is complicated by the possibility of neutron emission before the emission of an alpha particle.] The experimental values of a are in fair numerical agreement with the Fermi gas model if the nucleons at the top of the Fermi sea have an effective mass of 0.5. A basis for an explanation why a is not a completely smoothed function of nuclear mass is the variation of the average nucleon-level spacing at the top of the Fermi sea because of nuclear shell structure.

* Work done under the auspices of the U. S. Atomic Energy Commission.

T13. Mechanism of the Direct Interaction Process.* R. J. GRIFFITHS AND R. M. EISBERG, *University of Minnesota.*—The standard model of the direct interaction process pictures a collision between the incident nucleon and a nucleon at the edge of the target nucleus. The incident or struck nucleon immediately escapes, carrying away most of the incident energy. Occasionally, for such a process, both the incident and the struck nucleon should escape and (except for the effects of the momentum of the struck nucleon and of refraction in leaving the nucleus) the angle between the two escaping nucleons should always be 90°.[1] In order to check these assumptions, and to aid in differentiating between several other direct interaction models which do not imply a 90° angular

correlation, we have investigated the emission of two fast (10 Mev$\leq E\leq$30 Mev) protons in time coincidence from $_{29}$Cu bombarded by 40-Mev protons. The observed angular correlation is peaked at 90°, with full width at half-maximum about 35°. For approximately every 100 fast protons entering one detector, there is a second proton emitted in time coincidence at some angle. These data should yield information about the struck nucleon's momentum distribution and about the density of protons at the nuclear surface.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. M. Eisberg, University of California Radiation Laboratory Report: UCRL-2240 (June, 1953).

T14. Energy and Spin Systematics of Even-Even Nuclei with $22\leq N<50$.* D. M. VAN PATTER, *Bartol Research Foundation.*—Recently, new information regarding the energy levels of even-even nuclei has become available,[1,2] indicating that the energy ratio E_2/E_1 of the second to first excited state drops below 2 in the region $30\leq N\leq 40$, as has been pointed out.[2] Examination of the evidence concerning the energies and spins of the second and third excited states of nuclei in the region $22\leq N<50$ has revealed a possible systematic trend for the spin of the second excited state. For nuclei with $22\leq N<30$, the spin of the second excited state is always 4+ when measured. For nuclei with $32\leq N<50$, the spin of the second excited state is always 2+ when measured, omitting the low-lying 0+ states in Ge^{70} and Ge^{72}. There is some indication that the 4+ and 2+ levels may cross over at $N=30$ to 32. Some implications of these possible systematic trends will be discussed.

* Assisted by the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] R. M. Sinclair, Phys. Rev. 107, 1306 (1957).
[2] D. J. Horen and W. E. Meyerhof, Bull. Am. Phys. Soc. Ser. II, 2, 396 (1957).

SATURDAY MORNING AT 9:15

Shoreham, Main Ballroom

(J. M. BURGERS presiding)

Fluid Dynamics

TA1. Cylindrical Shock Waves from Exploding Wires. II. F. D. BENNETT, *Ballistic Research Laboratories.*—A simple technique has been found for rendering visible the shock wave formed by an exploding wire after the shock has separated from the luminous contact surface. A small, plane mirror is placed just behind the wire so as to be perpendicular to the axis of the optical system. Thus the reflected image of the wire explosion coincides with the disturbance itself when seen through the slit by the camera lens. Rotating mirror pictures taken under these conditions show very clear outlines of the parabolic shock wave as it propagates ahead of the luminous contact surface. In the examples shown, separation of the shock and contact surface is complete by about one μsec. Beyond this time the shock is clearly nonluminous and ordinarily would not be visible. While the rotating mirrorgrams suggest that the shock is luminous, it must be emphasized that refraction of the back lighting produced by the mirror is responsible for the optical image of the shock. Comparison of shock trajectories with predictions from the similarity solutions for strong shock waves obtained by S. C. Lin may be interpreted as showing that the shock is receiving additional energy while traversing the early part of its path. After this phase both shock and contact surface accurately obey the parabolic law over intervals of several microseconds.

TA2. Structure of a Shock Wave in Fully Ionized Hydrogen.* D. A. TIDMAN, *University of Chicago.*—The Fokker-Planck equation is used to examine the structure of a shock wave in fully ionized hydrogen in the absence of a magnetic field. This is done by assuming a bimodal Maxwellian distribution for the protons in the interior of the shock and noting that the electrons are in thermal equilibrium with themselves but not necessarily with the protons in this region. The method is essentially an extension of that used by Mott-Smith in his analysis of the Boltmann equation for a shock wave in an un-ionized gas.

* This work was supported by the U. S. Atomic Energy Commission.

TA3. Vibrational Relaxation and Chemical Reaction behind Shock Waves in N_2O.* W. R. SMITH, *Princeton University.*—Shock waves ranging in speed from Mach 2 to 10 in N_2O have been measured interferometrically. The earlier vibrational relaxation times of Griffith *et al.* have been extended to Mach 5.5. A plot of τ (atmospheric) *versus* T^{-1} may be represented by a straight line. An exothermic chemical reaction zone several cm thick follows behind a shock of speed Mach 7. For higher Mach numbers the rate of reaction increases and the reaction zone shortens. Near Mach 9 the reaction zone is compressed to a surface in the flow almost directly behind the shock. Across this surface, the density ratio drops almost discontinuously from its value behind the shock to its final value several mm from the shock. An interpretation of the density ratio can be made in terms of the concentrations of the chemical species present.

* Supported by the Office of Naval Research.

Post-Deadline Papers, If Any

SATURDAY MORNING AT 9:15

Sheraton-Park, Exhibit Room

(E. K. PLYLER presiding)

Microwave and Optical Spectroscopy

U1. Description of a Raman Type Two-Level Maser. ALI JAVAN, *Columbia University.*—In a two-level system, if two photons of different frequencies are present with their frequency difference close to the energy separation of the two levels, in the presence of proper types of matrix elements, a transition can take place from the lower level to the upper level in which the larger frequency photon is absorbed and the lower frequency photon is emitted. In the reverse transition, the role of absorption and emission of the photons is interchanged. This process, in the presence of a positive temperature, will produce amplification at the lower frequency. This effect will be treated quantum mechanically, and the probability of the spontaneous emission entering in the noise figure of this type of amplifier will be derived. Also the formula for magnetic susceptibility at the amplifying frequency for a paramagnetic ion of spin $\frac{1}{2}$ in an external magnetic field will be presented. The theoretical and practical application of this system to special cases of ferrites and systems with electric or magnetic dipole transitions will be discussed.

U2. Microwave Oscillators Stabilized on Superconducting Cavities.* J. N. KIDDER AND W. M. FAIRBANK, *Duke University.*—Two 3 cm microwave oscillators have been stabilized on superconducting cavities. The stabilizing circuit is a modification of the system described by Pound[1] using a 30 mc/sec intermediate frequency. The cavities were pressed from tin, polished with alundum, annealed, and soldered with indium. The cavities have a Q of 6×10^8. The beat frequency between the klystrons was used to observe the stability. The frequency was measured by counting cycles over a one second period. The beat frequency showed a root mean square deviation of approximately 10 cycles per second over short time intervals and 100 cycles per second over long time intervals. This stabilizing system has been designed for flow experiments with liquid helium II. The cavities will serve as level indicators to measure the pressure drop along a capillary. The change of cavity resonant frequency with change of helium level in the cavity is approximately 1 A per cycle per second.

* This research was supported jointly by the Research Corporation and the Office of Ordnance Research, U. S. Army.
[1] R. V. Pound, Rev. Sci. Instr. **17**, 490 (1946).

U3. Comparison of Wave Guide and Cavity Microwave Spectrometers.* YARDLEY BEERS, *New York University.*—A short section of wave guide is considered alternately as a true wave-guide absorption cell terminated by its characteristic impedance and as a high Q resonator. With the assumption of a detector which is linear in voltage, which usually is valid, it can be shown that in resonator operation the voltage signal-to-noise ratio is larger by a factor from about $(Q/2)^{\frac{1}{2}}$ to about $Q/2$, depending upon whether or not saturation of the sample is imminent and upon how the noise is divided between the oscillator and detector. If saturation is imminent, the input voltage to the resonator must be smaller by a factor of $Q^{\frac{1}{2}}$, and then a simple crystal video detector may not be adequate. A variety of evidence indicates that a considerable portion of the noise probably comes from the oscillator.

* Supported by the Air Force Office of Scientific Research and the Office of Naval Research.

U4. The Rotational Magnetic Moment of Ozone.* G. C. WEIFFENBACH, *Applied Physics Laboratory, The Johns Hopkins University* (introduced by C. K. Jen).—The rotational magnetic moment of O_3 was determined by measurement of the Zeeman splitting of six low $J(J\leq6)$ rotational transitions[1] in the microwave region. The measured g factors were used to determine the diagonal elements of the O_3 g tensor, applying theoretical results obtained by Schwarz. The rotational g factors were determined to be all negative, and unexpectedly large in magnitude, with g for the $1_{1,1}$ state ($g=-1.5390\pm0.0075$ in nuclear magneton units) the largest measured to date for a $^1\Sigma$ molecule. The g-tensor elements (determined by a least-squares fit to the measured g factors) are: $g_{xx}=-0.0891\pm0.0051$, $g_{yy}=-0.2207\pm0.0042$, $g_{zz}=-2.9889\pm0.0087$ with y the symmetry axis, and the x axis perpendicular to the plane of the molecule.

* This work supported by Bureau of Ordnance, Department of the Navy.
[1] The Zeeman splitting of the $2_{0,2}\rightarrow1_{1,1}$ transition was first reported by R. Trambarulo *et al.*, J. Chem. Phys. **21**, 851 (1953).

U5. ND_3 Inversion Lines in the Millimeter Region.* J. J. GALLAGHER, C. M. JOHNSON,† AND V. E. DERR, *The Johns Hopkins University.*—Nine lines have been found in a sample of ND_3 at a pressure of approximately 50 microns in the region from 114 000 mc to 130 000 mc. These lines are tetatively attributed to the inversion transition in the first excited vibrational state ($v_2=1$). A broad resonance region was found at pressures near one atmosphere by Loubser and Klein,[1] who gave the inversion as approximately 117 000 mc. The present investigation indicates that the inversion is more nearly 127 000 mc. Isotopic assignment of the lines of ND_3 was made on a basis of intensity deterioration caused by the introduction of NH_3 into the sample to produce partially deuterated ammonia. Calculations of line frequencies, for J values up to 12, of NH_2D and ND_2H based on constants given by Weiss and Strandberg[2] indicate that no lines of appreciable intensity lie in the region under investigation. A description is given of a Stark cell, suitable for the millimeter region, which has been used to assign tentative quantum numbers to the transitions.

* This work has been supported in part by WDAC and ARDC.
† Present Address: Electronic Communications, Inc., Baltimore, Maryland.
[1] J. H. N. Loubser and J. A. Klein, Phys. Rev. **78**, 348A (1950).
[2] M. T. Weiss and M. W. P. Strandberg, Phys. Rev. **83**, 567 (1951).

U6. Microwave Spectrum and Barrier to Internal Rotation of Methyl Germane.* VICTOR W. LAURIE,† *Harvard University and National Bureau of Standards* (introduced by D. R. Lide).—The $J=0\rightarrow1$ and $1\rightarrow2$ transitions of a number of isotopic species of methyl germane have been measured. From the rotational constants obtained, the following structure has been calculated: $d_{CH}=1.089$ A, $d_{GeH}=1.534$ A, $d_{C-Ge}=1.9453$ A, $\sphericalangle HCH=108°14'$, $\sphericalangle HGeH=108°38'$. The $K=1$ transitions of the asymmetric species are split by internal rotation. With the assumption of a threefold sinusoidal potential, an internal barrier of 1235 cal/M has been calculated from the observed splittings.

* This work was supported in part by the Office of Naval Research through Harvard University.
† National Research Council Research Associate 1957–1958.

U7. Microwave Spectrum of Trimethylphosphine and Trimethylarsine. DAVID R. LIDE, JR., *National Bureau of*

Standards.—Microwave transitions from molecules in the ground states of $(CH_3)_3P$ and $(CH_3)_3As$ are found to follow a symmetric-rotor pattern with rotational constants 5816.24 and 4724.98 Mc, respectively. The value of eqQ (As^{75}) is -203.15 Mc. Stark effect measurements on $(CH_3)_3P$ give a dipole moment of 1.192*D*. Measurements on $(C^{13}H_3)(C^{12}H_3)_2P$ give the following structure for trimethylphosphine: $r_{CP}=1.841$ A, $\measuredangle CPC=99.1°$. $\measuredangle HCH=107°$. The satellite lines which surround each transition have been assigned to excited vibrational states, and vibrational frequencies have been determined from relative intensity measurements. Some information on the internal rotation of the CH_3 groups has been obtained.

U8. *S* Band Microwave Spectrum $N^{15}O_2$.* J. ROSENTHAL, *New York University.*—A rotational transition of $N^{15}O_2$, predicted by G. R. Bird,[1] has been observed in the *S* band microwave region. Using a Stark-modulated spectrometer, the following multiplet was discovered: (a) 4321, (b) 4243, (c) 4082, (d) 3900, (e) 3759, and (f) 3661 mc/sec. The precision is approximately 1 mc/sec and will be increased in further measurements. It is suggested that the above are magnetic fine structure components for the $8_{08}\rightarrow 7_{17}$ rotational transition. These data offer further confirmation of a combination rule, arrived at independently by Bird[2] and C. C. Lin. It is seen that the frequency difference of 239 mc/sec between lines (a) and (c) also holds for (d) and (f). A search will be made for the $22_{1,21}\rightarrow 21_{2,20}$ transition.

* Work supported by the Office of Scientific Research, U. S. Air Force.
[1] Private communication.
[2] G. R. Bird, J. Chem. Phys. **25**, 1040 (1956).

U9. Theory of the Microwave Absorption in Compressed Oxygen.* MASATAKA MIZUSHIMA, *University of Colorado.*—Recently Maryott and Birnbaum[1] measured the absorption by oxygen gas of up to 40 atmospheres at frequencies 2.3 kMc, 9.1 kMc, and 23.3 kMc. Their results showed a large discrepancy from the expected values given by low-pressure values of line width parameter and Van Vleck-Weisskopf's theory.[2] In this paper an explanation of this discrepancy is given by considering a nonspherical intermolecular potential between oxygen molecules. It is found that we can still use low-pressure values of line width parameter and Van Vleck-Weisskopf's theory, but frequency and intensity of resonant absorption and intensity of nonresonant absorption is very different at higher pressure. Also an induced absorption at 3 kMc region is expected.

* This research has been supported by the National Science Foundation.
[1] A. A. Maryott and G. Birnbaum, Phys. Rev. **99**, 1886 (1955); (private communication).
[2] J. H. Van Vleck and V. F. Weisskopf, Revs. Modern Phys. **17**, 227 (1945).

U10. Vibrational Frequencies of Excited Electronic States of Diatomic Molecules. ROBERT W. KEYES, *Westinghouse Research Laboratories.*—This paper derives an approximate relationship between the vibrational frequencies, ω_e, and the internuclear distances, r_e, of excited states of diatomic molecules in terms of parameters determined by measurements on the ground state. The model used assumes that (1) the internuclear potential function can be formed by adding the contributions from each valence electron, (2) the contribution of any electron in a bonding orbital can be represented by a Morse function, (3) the contribution of an antibonding electron to the potential is represented by the same function, except that the sign of the attractive term of the Morse potential is reversed, and (4) the various electronic states can be sufficiently characterized by a single parameter, p, which is the fraction of electrons in bonding orbitals. By using the ω_e, r_e, and anharmonicity of the ground state to determine the constants of the Morse function, a relation between ω_e and r_e for excited states of the molecule and for the molecular ion can be obtained. Values of the anharmonicity of the other states are also predicted. Comparison with measured parameters will be given.

U11. Further Modulation Studies of Infrared Absorption Spectra.* JAMES C. GILFERT AND DUDLEY WILLIAMS, *The Ohio State University.*—The earlier techniques[1] for observing infrared spectra by pressure modulation have been refined to the point where they can be employed in high resolution work. In the work to be reported the total pressure in an absorption cell is periodically varied at the rate of 8 cycles/sec. At this modulation rate the compression and expansion processes are nearly adabatic. The resulting periodic temperature variation results in a periodic variation in the populations of the various rotational energy levels. This effect can be observed in the wings of the vibration-rotation bands. With a spectrograph of high resolving power, it is possible by modulation techniques to observe rotational lines involving transitions between the higher rotational levels that are not observed in conventional spectra. A comparison between observed and predicted spectra will be given for carbon monoxide.

* Supported in part by Air Force Cambridge Research Center.
[1] Gilfert and Williams, Bull. Am. Phys. Soc. Ser. II, 2, 212 (1957).

U12. Blue Nitric Oxide Afterglow.* C. A. BARTH, W. J. SCHADE, AND J. KAPLAN, *University of California, Los Angeles.*—The blue nitric oxide afterglow was excited in a gas mixture containing approximately 95% helium, 4% nitrogen, and 1% oxygen in a continuous flow system. The nitric-oxide beta bands of the resulting blue afterglow were examined in the green spectral region with a high-speed spectrograph. It was found that in the blue afterglow containing helium, the intensity distribution of the NO β bands favored lower vibrational levels than did the distribution of these bands in a blue afterglow containing only oxygen and nitrogen. This lowering of the vibrational population of the $B^2\pi$ state, the upper state of the NO β bands, by a rare gas is similar to the rare-gas intensity shift of the first positive bands in the nitrogen afterglow. This suggests that the excitation mechanism of the blue NO afterglow is analogous to the mechanism that excites the nitrogen afterglow and hence involves an intermediate state: $N+O+M\rightarrow NO^*+M$; $NO^*+M\rightarrow NO(B^2\Pi)+M$.

* Supported in part by the Air Force Geophysics Research Directorate.

U13. Fine Structure Pressure Effects.* L. KLEIN AND HENRY MARGENAU, *Yale University.*—The Van der Waals dipole-dipole perturbation energy is calculated for the fine structure levels of an alkali atom interacting with noble gas atoms. A general expression for the interaction energy caused by n simultaneously acting perturbers is developed for the $^2P_{\frac{1}{2}}$ and $^2P_{\frac{3}{2}}$ levels of the alkali atom. Shift and broadening of these two components are calculated as functions of noble gas density by the use of a statistical theory. It is found that the theory predicts a red shift which is nearly linear with density, the $^2P_{\frac{1}{2}}$ component being shifted slightly more than the $^2P_{\frac{3}{2}}$. This is in agreement with the experimental data for heavy noble gases.[1] The half-widths predicted are slightly less than the experiments indicate, but the discrepancy is within the limits of accuracy of the theory. Because of neglect of exchange effects and higher than dipole interactions, the treatment is restricted to densities below 100 rd.

* Work supported by the Air Force Research and Development Command.
[1] S. Ch'en and M. Takeo, Revs. Modern Phys. **29**, 20 (1957).

U14. Optical Spectra Excited in Noble Gases at High Pressure by Alpha Particles.*† W. R. BENNETT, JR.,‡ AND C. S. WU, *Columbia University.*—The principal lines encountered in most helium, neon, and argon samples were nitrogen impurity bands. The first negative system of N_2^+ was encountered in helium and neon, and the second positive sys-

tem of N_2 was found in helium and argon. The most striking aspect of our data was the persistence of the N_2^+ first negative system down to one part nitrogen in 10^9 helium. The excitation of such small nitrogen concentrations in helium may be explained by charge exchange collisions with He_2^+ molecular ions. At higher nitrogen concentrations the excitation of N_2^+ is believed also to be caused by collisions with $^3S_1$ metastables. Evidence is presented which indicates that at low-nitrogen concentrations in argon, the excitation of the second positive system is mainly caused by $^3P_2$ metastables. A more detailed discussion of the impurity excitation processes will be given. In addition the spectra (2400 to 5500 A) excited in all of the noble gases and taken under conditions of ultra-high purity (less than one part in 10^9 for most contaminants) will be presented.

* Preliminary reports of this work were given in Bull. Am. Phys. Soc. Ser. II, 1, No. 1, 68 (1956); Bull. Am. Phys. Soc. Ser. II, 2, No. 1, 54 (1957). The method used for purification is discussed by W. R. Bennett, Jr., Rev. Sci. Instr. 28, 12, 1092 (1957).

† This work partially supported by the U. S. Atomic Energy Commission.

‡ Present address: Yale University.

SATURDAY MORNING AT 9:15

Shoreham, West Ballroom

(A. KLEIN presiding)

Theoretical Physics IV; Mesons and Hyperons

V1. Coulomb Effect in Boson Emission. MICHAEL J. MORAVCSIK,* *Brookhaven National Laboratory.*—The effect of Coulomb interaction in boson emission is studied as part of a program aimed at evaluating the electromagnetic corrections in the controversial low-energy pion photoproduction from deuteron. The present problem is that of solving the Klein-Gordon equation in the potential caused by an extended charge distribution. The Schrödinger equation with point source gives the customary Coulomb penetration factor. This is modified especially by the extended source effect since in the cases of practical interest the de Broglie wavelength of the emitted boson can often be of the same order of magnitude as the size of the source. Since the charge distribution of the emitting source is not known, several plausible or extreme distributions are considered. The relativistic effects are caused by change in kinematics and to the quadratic nature of the Klein-Gordon equation. Both S-wave and P-wave pions are considered. In the case of pion emission by a nucleon the deviation from the traditional penetration factor is not large at the energies which are of interest in the interpretation of experiments.

* Present address: Radiation Laboratory, Livermore, California.

V2. Effect of Meson-Meson Scattering Term in *ps-ps* Meson Theory on Low-Energy Pion-Nucleon Scattering and Threshold γ-Pion Production. MASAO SUGAWARA, *Purdue University.*—The present author recently proposed a method[1] of constructing a static Hamiltonian from the relativistic *ps-ps* meson theory and of analyzing it without using the perturbation expansion. The same has now been applied to the case where the meson-meson scattering term exists. Another improvement is that the argument is presented to show the Foldy transformation is the unique one generating a valid static Hamiltonian, though it was left undetermined in the previous work.[1] We investigated both low-energy S- and P-wave pion-nucleon scattering and threshold γ-pion production, adopting the one-meson approximation in the Chew-Low-Wick formalism. The conclusions are that (a) as regards S-wave scattering, the meson-meson scattering term can attain as much meson-pair damping as is desired and (b) it affects also P-wave scattering so that the coupling constant determined by the Chew-Low plot will be much reduced, thus possibly explaining the difference between values of the coupling constant empirically determined by these two methods. The renormalizations are not carried out rigorously and effects of all other strange particles are not taken into account.

[1] M. Sugawara, Progr. Theort. Phys. (Kyoto) 18, 383 (1957).

V3. Application of the Spin-Flip Dispersion Relations to the Minami Ambiguity for the Pion-Nucleon Scattering.* R. M. STERNHEIMER AND S. J. LINDENBAUM, *Brookhaven National Laboratory.*—The dispersion relations for the derivative of the spin-flip amplitude a_3 at zero scattering angle have been applied to the Minami phase shifts for the pion-nucleon scattering, in a calculation similar to that of Davidon and Goldberger[1] for the Fermi and Yang phase shifts. The Minami phase shifts lead to a dependence of y *vs* x which disagrees with the predicted straight-line behavior deduced from the dispersion relations. Here $x \approx$ laboratory total energy of pion in units of the pion rest energy, and y involves $\mathrm{Re}(a_3)$ and two integrals over the values of $\mathrm{Im}(a_3)$ at all energies.[1] The Minami solution is therefore inconsistent with the dispersion relations. The same calculation was also carried out for a new set of phase shifts, not previously considered, which is obtained by applying the Minami transformation ($S \leftrightarrow P$, $P \leftrightarrow D$) to the Yang phase shifts. These new phase shifts are also incompatible with the dispersion relations. Thus the Fermi solution is the only one which satisfactorily describes the pion-nucleon scattering at low energies up to ~300 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] W. C. Davidon and M. L. Goldberger, Phys. Rev. 104, 1119 (1956).

V4. Dispersion Relations for Pion-Nucleon Scattering.* DONALD A. GEFFEN, *Carnegie Institute of Technology.*—The usual dispersion relation for $D^{(1)}(\omega) = \frac{1}{2}[D_+(\omega) + D_-(\omega)]^3$ has been modified by introducing another energy denominator in the principal part integral appearing in the dispersion relation. This introduces another subtraction of the real part of the scattering amplitude at an arbitrary energy ω_0. By letting ω_0 approach the meson mass, the dispersion relation takes the form,

$$D^{(1)}(k^2) = D^{(1)}(0) + k^2\left(\frac{\partial D^{(1)}}{\partial k^2}\right)_{k^2=0} + I(k^2) - \frac{k^4}{\omega^3}\frac{\mu}{M}f^2,$$

where $I(k^2)$ is the principal part integral over the total cross sections. The number, $\partial D^{(1)}(0)/\partial k^2$ is calculated from the dispersion relation itself. With this value for $\partial D^{(1)}(0)/\partial k^2$, there is no discrepancy between theoretical and experimental values of $D^{(1)}$ that could not be explained by reasonable experimental errors. However, the theoretical value for $\partial D_-(0)/\partial k^2$ disagrees with the energy dependence for pi-minus phase shifts currently believed. Results of a similar calculation for $D^{(3)}$ will also be discussed.

* Supported by the U. S. Atomic Energy Commission.

[1] Goldberger, Miyazawa, and Oehme, Phys. Rev. 99, 986 (1955).

V5. Determination of the Pion-Nucleon Scattering Amplitude from Dispersion Relations and Unitarity.—S. MANDELSTAM, *Columbia University.*—A method is proposed for using generalized dispersion relations, together with unitarity, to determine the pion-nucleon scattering amplitude. In addition to the usual dispersion relations, one needs dispersion relations in which the energy is kept constant and the momentum transfer varies. The unitarity condition is taken in the *one-meson* approximation; in addition, some use has to be made of the unitary condition for the process $N+\bar{N}\to 2\pi$. The method requires a knowledge of the crossing term, and, as in the Chew-Low treatment of the problem in the static theory, an iteration procedure can be used in which the crossing term for the nth iteration is taken from the $(n-1)$th iteration. A coupling constant corresponding to pion-pion interaction has to be introduced in addition to the pion-nucleon coupling constant; it can be determined by requiring that the sum of the S-wave scattering lengths at threshold agrees with experiment. The Castillejo-Dalitz-Dyson ambiguity occurs for the $S_{\frac{1}{2}}$ and $P_{\frac{1}{2}}$ states alone. The ghost states which appear when the crossing term is neglected may very possibly disappear when it is included, but this cannot be proved until the calculation is done.

V6. Scattering of Polarized Mu Mesons from Extended Nuclei.* G. RAWITSCHER, L. B. EMMONS, AND W. A. GIBSON, *University of Rochester.*—In view of the increasing interest in the polarization of *weak decay* products, the scattering of polarized mu mesons from the Coulomb field of an extended nucleus is calculated. The method consists in numerically computing (I.B.M. 650) the Dirac scattering wave functions by means of a partial wave expansion. The charge distribution adopted is the one used to describe the electron scattering on nuclei.[1] Results for the polarization as a function of scattering angle will be presented for various values of v/c and Z. The effect of the size of the *tail* and the radius of the charge distribution on the polarization will be analyzed and the results will be compared with the ones already known[2] for the various limiting cases of a point nucleus, uniform charge distribution, etc.

* This work has been supported in part by the U. S. Atomic Energy Commission.

[1] Yennie, Ravenhall, and Wilson, Phys. Rev. 95, 500 (1954).

[2] Sherman, Phys. Rev. 103, 1601 (1956); Franklin and Margolis, Bull. Am. Phys. Soc. Ser. II, 3, 51 (1958); Brown, Elton, and Mandl (to be published).

V7. Pion Decay and Possible Nonlocal Effects in the Theory of Fermi Interactions.* ALBERTO SIRLIN, *Columbia University.*—Possible nonlocal effects in the theory of Fermi interactions are studied phenomenologically. Under certain simple assumptions, an effective Hamiltonian is derived which reduces to the local $V-A$ interaction in the limit in which the momentum transfer between the two pairs of Fermi particles is very small. For larger values of the momentum transfer, corrective terms appear which may account phenomenologically for the deviations of the ρ value and the ratio $R=(\pi\to e+\nu)/(\pi\to\mu+\nu)$ from the predictions of the local $V-A$ theory. The pion and muon decays are analyzed in detail. Other weak processes are briefly discussed.

* This work was supported by the U. S. Atomic Energy Commission.

V8. Magnetic Moment of the Λ^0. WENDELL G. HOLLADAY, *Vanderbilt University.*—The charge, current, and magnetic moments of the Λ, Σ, and π fields transform as T_1 in isotopic spin space. Since Λ^0 has $T=0$, it follows that the magnetic moment of the Λ^0 caused by virtual π and Σ states vanishes, if charge independence obtains. The vanishing of the pionic contributions on the Λ^0 moment should therefore lead to a Λ^0 moment considerably smaller in magnitude than that of the neutron. The Λ^0 moment must arise from contributions that are scalars in isotopic spin space and could therefore be very enlightening as to the size of such contributions, which at present is rather perplexing with respect to the nucleon anomalous moments. Possible contributions to the Λ^0 moment will be discussed.

V9. Weak Decays and Isotopic Spin. D. C. PEASLEE AND M. KAWAGUCHI, *Purdue University.*—Consequences are considered of expressing weak interactions in terms of the two independent isotopic spins characterizing baryons. There are then four independent coupling constants g for each class of charged lepton decays. Under this assumption the lepton decay of K mesons implies lepton decay of at least some baryons besides n and p, though these may still be slightly below presently observed levels with a suitable choice of the g's. The absence of $\pi\to e+\nu$ can be interpreted simply by saying that one of the four g's is zero; the absence of $K\to e+\nu$ implies a similar rule which is less simple if the K-baryon interaction is not universal (as the π-baryon interaction is assumed). For weak pion emission the present scheme readily reproduces the $\Delta I=\frac{1}{2}$ results for Λ decay while at the same time allowing effective $\Delta I\geq\frac{1}{2}$ for Σ decay; it also predicts the Ξ lifetime directly from the known Λ lifetime. The slowing of $K^+\to 2\pi$ relative to $K^0\to 2\pi$ appears at least superficially fortuitous; but a wide range of charged to neutral $K\to 2\pi$ ratios (including the experimental value) can readily be encompassed.

* Assisted by the U. S. Air Force Office of Scientific Research.

V10. Parity-Conserving Interaction for K-π Decay. H. NICHOLS, *M.I.T.* (introduced by H. Feshbach).—A specific interaction Lagrangian is proposed which, to the first approximation in a perturbation expansion, accounts for the lifetimes and branching ratios in K-π decays. Since parity is rigorously conserved, the K meson is described as a parity doublet. The total Lagrangian is invariant under charge conjugation and time reflection. The strong interaction, of the form $g_S\varphi_K\sigma\chi_K\chi_\pi$, is a scalar in isotopic space and is invariant under parity conjugation (in order to have scalar and pseudoscalar K masses equal). The weak interaction, of the form $g_W\chi_K\chi_\pi$, allows a change in total isotopic spin of $\frac{1}{2}$ or $\frac{3}{2}$. The final-state pions are considered in plane-wave states. If one assumes that the pion-mode branching ratios in K^0 decays are equal to the corresponding ratios in K^+ decay, the theory will fit all the lifetime and branching ratio data; however, such a hypothesis is not necessary, for there is a range of possible K^0 branching ratios for which agreement with experiment can be obtained. Under this hypothesis, and with the weak interaction written $g_W(\sigma+\alpha\sigma_0)\chi_K\chi_\pi$, the following dimensionless constants are obtained: $g_S=0.7$; $g_W=2\times10^{-7}$; $\alpha=-0.15$. No account is taken of any of the K-decay modes involving neutrinos, nor of the production or scattering properties of the K particles.

V11. Binding Energy of the Hypertriton. D. G. COSTELLO AND J. T. JONES, JR., *North Texas State College.*—Recent, relatively accurate calculations by Downs and Dalitz[1] indicate that if the baryon interactions are represented by central Yukawa potentials, then the hypertriton is quite far from being symmetric for a range of the Λ^0-nucleon interaction equal to one-half of the pion Compton wavelength. We have assumed the phenomenological Λ^0-nucleon potential, determined by them for such a range, in calculating the binding energy of the hypertriton by use of the Morpurgo-Clark[2] variational technique. For asymmetric systems, the Morpurgo-Clark method has the disadvantage that the radial part of the trial function is assumed to be spatially symmetric. The result of our calculations, now being completed, will provide an indication of the validity of a slight modification of this method as applied to asymmetric systems. A valid modification would be of interest because it could be used, without great effort,

in determining properties of systems described by noncentral potentials.[2]

[1] B. W. Downs, Jr. (private communication).
[2] G. Morpurgo, Nuovo cimento 9, 461 (1952); A. C. Clark, Proc. Phys. Soc. (London) A67, 323 (1954).

V12. Production of Strange Particles by π-Nucleon and Photonucleon Interactions near Threshold.* ROBERT K. ADAIR, *Brookhaven National Laboratory.*—An investigation of the behavior of the π-nucleon and photonucleon reaction cross sections near the strange particle threshold shows that the variation with energy of the Λ^0-K cross section near the $\Sigma-K$ threshold depends strongly upon the relative parities of the Σ and the Λ^0 hyperons. In particular, if the elements of the Wigner R matrix are nearly stationary near the $\Sigma-K$ threshold, and if the decay of the compound system is nearly independent of its mode of formation, the variation of the Λ^0 and Σ cross sections is almost uniquely established from cross sections measured at one energy. The Λ^0 cross section will then exhibit strong cusps at the $\Sigma-K$ thresholds. Angular distributions and polarizations are discussed from the viewpoint of these assumptions. The photonucleon production of strange particles is shown to be closely related to the π-nucleon production, essentially because the same final state interactions are important. The strength and characteristics of these interactions lead to the conclusion that the matrix elements for photonucleon production of strange particles will, in general, be strongly affected in magnitude by the final state interactions and they will not be real, even at threshold.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:00

NBS, East Building

(R. M. TALLEY presiding)

Semiconductors

VA1. Green's Functions for Minority Carrier Flow in Semiconductors. M. SOLOW, *U. S. Naval Ordnance Laboratory.*—The flow of minority carriers injected at arbitrary points in a semiconductor can be studied by means of Green's functions. We have derived an explicit expression for the scalar Green's function for a three-dimensional semiconductor. This can be used to determine the effects of scalar sources; that is, sources which are changes in density of minority carriers in the bulk or on the surfaces. To handle vector sources such as diffusion currents, it is necessary to derive a tensor Green's function. We have attempted to do this for a three-dimensional semiconductor with arbitrary surface recombination velocity, s, by the method of vector eigenfunctions. A set of vector eigenfunctions is found, but for arbitrary s the eigenfunctions are not orthogonal caused by the nonseparability of the surface conditions. However, for the case of infinite s the vector eigenfunctions are orthogonal and are used to construct an explicit tensor Green's function. These scalar and tensor Green's functions should be useful in semiconductor problems where injection of minority carriers occurs at arbitrary points; some examples are noise phenomena* and photoconductivity.

* M. Solow, *Theory of Noise in a Multidimensional Semiconductor with a p-n Junction*, a dissertation (The Catholic University of America Press, Washington, D. C., 1957).

VA2. Electrical Characteristics of a Silicon End Constriction. M. GREEN, J. BANZHAF, AND I. N. GREENBERG, *U. S. Army Signal Engineering Laboratories.*—A rod (11 mm diameter $\times$20 mm long) of high purity, p-type, single crystal silicon of uniform resistivity (1900 ohm cm) showed a linear (ohmic) characteristic with both ends rhodium plated. A rectangular shaped constriction 11.0×0.7 mm^2 was formed at one end by grinding off part of the silicon and of the plating to a depth of 0.4 mm. The constricted specimen showed rectification characteristics which improved with decreasing temperature. At 78°K the resistance of the specimen decreased with increasing current for the blocking polarity, constriction positive, as well as for the injecting polarity, constriction negative. However the ratio of resistances (approximately 1.8 to 1) varied only slightly. At room temperature the transient behavior showed the characteristic logarithmic injection curve. Extraction of minority carriers for reverse polarity was either nonexistent or too weak to observe. The oscillograms showed no sign of injection at the large area rhodium plated end contact. The effect of the current density on the injection far outweighs that of the injecting area.

VA3. Low-Temperature Hole and Electron Mobility in Heavily Doped Silicon.* G. A. SWARTZ, *University of Pennsylvania.*—The hole Hall mobility of six p-type silicon samples and the electron Hall mobility of nine n-type silicon samples have been measured in the temperature region between 20°K and 85°K. The impurity concentrations varied from 6×10^{16}/cc to 3×10^{15}/cc and the impurities included boron, gallium, aluminum, arsenic, antimony, and phosphorus. The mobilities generally increased with decreasing temperature between 85°K and 30°K. Below 30°K, the mobilities were proportional to T^n where n varied from 1 to $\frac{1}{2}$. At 80°K, the mobilities resulting from phonon scattering and ion impurity scattering were subtracted from the total mobility using the usual reciprocal relationship. The resulting mobility in each sample was plotted against the number of neutral group III or group V in that sample at 80°K. This plot showed a reciprocal relationship which agrees with Erginsoy's[1] treatment of neutral impurity scattering.

* Research supported by the Office of Naval Research.
[1] C. Erginsoy, Phys. Rev. 79, 1013 (1950).

VA4. Theory of the PEM Effect in Compound Semiconductors. PAUL W. KRUSE, *Honeywell Research Center.*—The theory of the PEM effect in compound semiconductors as developed by Kurnick and Zitter[1] has been extended to include the effect of sample thickness and unequal surface recombination velocities at the front and back surfaces. The derivation includes the effect of large Hall angles and assumes small signals, total absorption at the front surface, and infinite sample extent in the plane normal to the direction of the radiation. Application is made to indium antimonide, where the short circuit current at 7000 gauss is found to be independent of thickness for thicknesses greater than approximately one diffusion length, but decreases as the thickness becomes less than a diffusion length. The short circuit current maximum occurs for low values of surface recombination velocities at the front surface and high values at the back for

thicknesses less than one diffusion length. For thicknesses greater than a diffusion length the short circuit current maximum occurs for low values at the front and is relatively independent of the back.

[1] S. W. Kurnick and R. N. Zitter, J. Appl. Phys. **27**, 278 (1956).

VA5. Far Infrared Cyclotron Resonance and Magnetoplasma Effects in InSp.* H. LIPSON, S. ZWERDLING, AND B. LAX, *Lincoln Laboratory.*—Reflection experiments as a function of magnetic field have been carried out on *n*-type InSb samples with carrier concentrations ranging from intrinsic to approximately 10^{14}/cc. These exploratory measurements were made using a reststrahlen monochromator with KCl, KBr, and KI plates, having wavelength ranges centering at 63μ, 83μ, and 94μ, respectively. The electron effective mass was found to be $(0.015\pm0.001)m_0$ after plasma effect corrections were made. Using reflection data at zero field and 30 000 gauss, the intrinsic electron concentration was found to be 10^{14}/cc and the dielectric constant ~17. Magnetoplasma effects at higher concentrations appeared as nonresonant absorption which increased with magnetic field near the plasma wavelength and, for very high electron concentrations, decreased with increasing field in agreement with the theory.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

VA6. Intervalence Band Transitions in GaAs.* R. BRAUNSTEIN, *RCA Laboratories.*—In *p*-type GaAs a number of absorption bands has been observed on the long-wavelength side of the intrinsic optical absorption edge. The same structure was found in all *p*-type samples regardless of the doping agent used to introduce free-holes. The evidence is that these bands are associated with absorption by free-holes and are not caused by the presence of unknown impurities or lattice defects. The strength of these bands is proportional to the hole concentration. At room temperature, there is a band at 0.42 ev, a partially resolved band at 0.31 ev, and the onset of a strong band at 0.25 ev. Aside from slight differences in the position of these bands, the spectral distribution in reminiscent of the structure seen in *p*-type Ge.[1] The main features of the spectra can be explained in terms of transitions between light-hole and heavy-hole bands and a band split off by spin-orbit interaction.[2,3] The spin-orbit interaction is ~0.34 ev. The temperature dependence of the spectra and the derived effective masses will be presented.

* Supported in part by U. S. Air Force.
[1] H. B. Briggs and R. C. Fletcher, Phys. Rev. **87**, 1130 (1952); **91**, 1342 (1953).
[2] A. H. Kahn, Phys. Rev. **97**, 1647 (1955); E. O. Kane, J. Phys. Chem. Solids **1**, 83 (1956).
[3] E. O. Kane, J. Phys. Chem. Solids **1**, 249 (1957).

VA7. Reversible Low-Voltage Breakdown in Stibnite.* J. R. DAVIS AND LEE GILDART, *University of Kentucky.*—Electric breakdown has been found to occur in both single-crystal and polycrystalline rods of stibnite containing up to 2.5% excess antimony at field strengths from 50 to 1000 volts/cm. This compares with breakdown fields in most insulators of the order of 10^6 volts/cm. The breakdown in stibnite establishes an electrically traceable low-resistance path through the material which at room temperatures is essentially permanent but which is rapidly annealed out when the sample is heated to about 300°C. After the temperature cycle the sample is apparently restored to its original state. In these samples the breakdown time is less than one microsecond and the resistance decreases from about 10^{10} ohms to about 10^4 ohms. Prebreakdown pulses are observed like those reported by McKay[1] in silicon *p-n* junctions. Breakdown has also been produced in devitrified thin films of stibnite, but the fields required are much greater and the resistance change less pronounced.

*This research has been supported by the Air Force Office of Scientific Research.
[1] McKay, Phys. Rev. **94**, 877 (1954).

VA8. Surface Potential, Field Effect Mobility, and Surface Conductivity of ZnO. H. J. KRUSEMEYER, *Bell Telephone Laboratories.*—Measurements were made at 300°K on as-grown and lithium-doped crystals, both in dry O_2 and high vacuum. The surface charge was changed by illumination with uv. Surface potentials of crystals with diameters down to 0.002 cm were measured by the Kelvin method with a sensitivity of 0.002 volt. The neutral point was determined by comparing the measured and calculated dependence of conductivity on surface potential. Application of a transverse electric field produces a fast effect in less than 50 μsec and a slow effect in which part of the conductivity change decays with a time constant from minutes to hours depending on ambient and surface potential. This is thought to be caused by a change produced by the field in the number of holes diffusing to the surface when the crystal is illuminated and a change in oxygen sorption when it is not. Field effect mobility increased with increasing surface potential from a value which is sometimes smaller than one to a maximum between 70 and 150 $cm^2\ volt^{-1}\ sec^{-1}$ and decreases again when the Fermi level crosses the conduction band edge. A quantitative treatment using the photoconductivity data of Collins and Thomas and the surface potential and mobility data presented here yields a hole diffusion length larger than 1000 A and a ratio of hole surface trapping velocity to diffusion constant of $1.7\times10^5\ cm^{-1}$.

VA9. Field Localization in Nonrectifying Contacts. M. A. LAMPERT, *RCA Laboratories.*—An electric field applied across an insulator with plane-parallel, nonrectifying contacts is ordinarily either uniformly distributed (Ohm's law currents) or increases gradually toward the anode (space-charge-determined currents). However, when the field at the cathode exceeds E_c, the critical field which imparts a drift velocity to the free carriers equal to their random thermal velocity, then the current is constant and equal to the random thermal current from the electrode into the insulator. The majority carrier depletion accompanying current saturation shifts the field distribution toward the cathode, the field now *decreasing* monotonically from cathode to anode. For a neutral contact (energy bands flat up to the contact interface) at voltages $V>E_cL$, with L the cathode-anode spacing, the excess voltage $V-E_cL$ localizes near the cathode for a sufficiently high total number of traps in the insulator. If, at thermal equilibrium, the bands bend down at the contact, then the critical field E_c' for the onset of such field localization is larger or smaller than n_fE_c/n_0 depending on whether the field-dependent mobility is smaller or larger, respectively, than the low-field mobility; n_f and n_0 are the free carrier densities at the cathode interface and in the neutral bulk, respectively.

VA10. Blocking-Electrode Static Space Charge Distributions. J. ROSS MACDONALD, *Texas Instruments.*—Positive and negative charge concentrations, potential, and electric field dependence on applied potential and distance from electrodes are given for both positive and negative charge carriers mobile and for mobile charges of only one sign with arbitrary bimolecular recombination for a finite-length, one-dimensional sample between two electrodes blocking for mobile carriers and for a semi-infinite sample with blocking electrode at the origin. Previous exact solutions for the cases of noncombining mobile carriers of both signs[1-3] are compared with accurate and approximate results for the one-mobile cases. In the one-electrode, one-mobile case, very high fields are produced

with low applied potential near the electrode when mobile charges concentrate there, and an approximate exhaustion layer (similar to that in reverse-biased *pn* junctions) is formed when mobile charge is drawn away from the electrode. Both effects occur in the one-mobile, two-electrode case but charge concentrations and fields are much lower for the same applied potential over the entire applicable potential range.

[1] G. Jaffé, Ann. Physik **16**, 217 (1933).
[2] J. R. Macdonald, J. Chem. Phys. **22**, 1317 (1954).
[3] J. R. Macdonald and M. K. Brachman, J. Chem. Phys. **22**, 1314 (1954).

VA11. Bombardment Conductivity in Rhombic Sulfur. BARRIE S. H. ROYCE, *King's College London**(introduced by R. Smolushowski).—Solid conduction counting techniques have been used to investigate the response of crystals of rhombic sulfur to alpha- and beta-particle irradiation. The crystals used were grown from solution in carbon disulfide at 0°C and were selected on the basis of the absence of obvious growth flaws, a total of 43 being examined by the counting techniques. Conduction pulses could only be obtained in 24 cases with α bombardment and none of the crystals gave detectable pulses with β particles. Experiments have been performed to determine the sign of carrier causing conduction, the dependence of counting behavior on field and of pretreatment. The observed conduction pulses differ in three main respects from those obtained with other solid conduction counters. There exists a critical field below which no pulses can be observed, the counting rate starts at zero under most circumstances and varies with time; depolarization pulses are not observable although apparently a polarization field is established in the crystals. It is proposed that these effects may be explained in terms of high field regions in the crystals.

* Now at Carnegie Institute of Technology.

VA12. Photoconductive and Photovoltaic Effects across Semiconductor-Surface Depletion Layers. W. W. GÄRTNER AND H. METTE, *U. S. Army Signal Engineering Laboratories.*—The photocurrents and photovoltages across a large area junction at a semiconductor surface are analyzed as a function of the impurity distribution in the semiconductor perpendicular to the surface. In particular it is shown that under certain conditions the photoconductive decay time becomes independent of the bulk lifetime and may be shorter than 10^{-10} sec for germanium and silicon.

VA13. Metal-to-Semiconductor Interfacial Photoeffects on Silicon. H. METTE AND W. W. GÄRTNER, *U. S. Army Signal Engineering Laboratories.*—The photoconductive and photovoltaic properties of a junction between a high-resistivity *N*-type silicon wafer and a transparent rhodium film are described. Photocurrent is shown as a function of light intensity, wavelength, reverse voltage, and temperature. Photovoltage is given in dependence on light intensity and wavelength. Response time is correlated with material properties and geometry. A preliminary account is given of experiments with other metal films and with different impurity distributions perpendicular to the surface.

VA14. Infrared *p-n* Junction Electroluminescence of Cuprous Oxide. R. FRERICHS AND R. M. HANDY, *Northwestern University.*—Cuprous oxide irradiated with visible light emits an infrared luminescence extending from 0.8 to 1.2 microns which was first observed by M. Seibt. We have obtained this invisible band at a *p-n* junction between Cu_2O and SnO_2 in electroluminescence. One electrode of the system consists of a copper plate (OFHC-copper) partly oxidized at 1000°C and subsequently cooled in high vacuum. Conducting glass (*n*-type SnO_2) with a few drops of castor oil pressed against the glossy red *p*-type Cu_2O layer forms the second electrode. With an alternating potential of 2000 cycles and a few hundred volts applied to the system, the cuprous oxide emits the infrared band over the whole area of contact. It is observed with an image converter. Simultaneous recording of the exciting current and of the emission (observed with a DuMont I-R photomultiplier) shows that the emission is approximately in phase with the voltage and brightest when the copperplate is positive. A second weaker maximum is observed in the opposite phase. If the system is first connected to a dc field of a few hundred volts and then switched to the ac field the emission is temporarily enhanced by a factor of 5 if the copper is positive and subdued by a factor of ½ in the opposite direction of the dc field. The stable light level is restored within a short time.

VA15. Preparation of Thin Single Crystal Semiconductor Films by Photoelectric Etching.* W. A. ALBERS, JR., AND J. E. THOMAS, JR., *Wayne State University.*—Under proper biasing conditions, the etching current in an electrolytic cell having a semiconductor as one electrode is determined by the flow of minority carriers to the surface of the semiconductor.[1] If penetrating light is used to inject minority carriers into the semiconductor, the injected carrier density per unit area of illuminated surface is proportional to the thickness. Therefore, if a germanium electrode is illuminated with light which has passed through a germanium filter comparable to the electrode thickness, the etching current density will be greater at the thicker regions. Consequently, as etching progresses, the sample automatically approaches uniform thickness. Employing these principles, large area thin single crystal films of *n*-type germanium have been prepared which are of the order of one micron thick. Films with an average thickness of three microns exhibit uniformities of about 50% of their maximum thickness while ten micron films are uniform to about 20%. These results have been obtained without any effort to adjust the distribution of light intensity. The experimental technique and preliminary observations of the properties of thin *n*-type germanium films will be presented.

* Supported in part by the Air Force Office of Scientific Research.
[1] W. H. Brattain and C. G. B. Garrett, Bell System Tech. J. **34**, 129 (1955).

VA16. ac-dc Electroluminescence. W. A. THORNTON, *Westinghouse Electric Corporation.*—The enhancement of electroluminescence by the superposition of ac and dc voltages is observed in certain electroluminescent zinc sulfide powder phosphors. The light emission L_B with both exciting voltages acting simultaneously is measured together with L_{ac} and L_{dc}, the light emissions because of each voltage acting separately. Values of the ratio $R=L_B/(L_{ac}+L_{dc})$ generally exceed unity (enhancement) except in the case of very low dc voltage, where quenching ($R<1$) occurs. Peak enhancement occurs where $L_{ac}\sim L_{dc}$. The experimental cells are conventional phosphor-plastic dispersions; a high phosphor-plastic weight ratio is used to get dc response. Wave form and transient measurements imply a reservoir of ionized luminescence centers and trapped electrons maintained by the dc field. During the half-cycle when the ac field is of opposite polarity (bucking the dc field), forced recombination of the trapped electrons and centers and the emission of light occur; during the other half-cycle no light output is observed and replenishment of the ionized centers and trapped electrons occurs. Spectral measurements show that the added light ($L_B-L_{ac}-L_{dc}$) is characteristic of the ac electroluminescence rather than the dc electroluminescence, as the above mechanism dictates.

SATURDAY AFTERNOON AT 1:30

Shoreham, West Ballroom

(M. SHAPIRO presiding)

Cosmic Rays; Astrophysics

W1. Estimate of Particle Momenta in Nuclear Emulsions Exposed under High Magnetic Fields.* Y. B. KIM, *University of Washington.*—With nuclear emulsions exposed under multihundred-kilogauss fields[1] the magnetic deflection and Coulomb scattering can be utilized conjunctively in the estimate of particle momenta. For a track divided into n equal cells h, the observed deflection x_i in each cell consists of magnetic deflection $\theta_m=(300ZHh)q=k_m q$, Columb scattering $\theta_c=(G|Z|\beta^{-1}h^{\frac{1}{2}})q=k_c q$, and Gaussian spurious error θ_s. The magnetic and Coulomb estimates of q (inverse momentum $1/p$) are obtained from $q_m=M\bar{x}/k_m$ with $\sigma_m^2=q^2K^4/(\gamma^2K^2+2)$, and

$$q_c=[\Sigma(x_i-\bar{x})^2/(n-1)-\theta_s^2]^{\frac{1}{2}}/k_c$$

with

$$\sigma_c^2=q^2K^4/2(n-1),$$

where $K^2=1+(\theta_s/\theta_c)^2$, $\gamma^2=n(k_m/k_c)^2$, M depends on $\bar{x}$ and other constants and is obtainable from a prepared graph. Since it can be shown that q_m and q_c are two *independent* estimates of q, the weighted mean,

$$q_w=(\sigma_c^2q_m+\sigma_m^2q_c)/(\sigma_m^2+\sigma_c^2);\quad \sigma_w^2=q^2K^4/(\gamma^2K^2+2n),$$

provides an estimate better than either q_m or q_c. Although the weighted mean contains the unknown q, it can be obtained from a prepared graph knowing q_m, q_c, and other constants.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] A pulsed magnet equipment designed for nuclear emulsion exposure under a field of about 200 000 gausses is being constructed in this laboratory.

W2. External Geomagnetic Field. A. BEISER AND S. A. KORFF, *New York University.*—Simpson and others have shown that the geomagnetic coordinate system derived from cosmic-ray measurements differs from that obtained from measurements of the earth's magnetic field. The effective external geomagnetic dipole influencing the motion of cosmic rays appears to be shifted ~45° westward geographically from the conventional geomagnetic dipole. We have considered a simplified model of the interaction between the rotating equatorial dipole component $\mathbf{M}_{eq}$ of the field of internal origin and interplanetary matter, and find that the magnetic moment $\mathbf{M}_{eq}{}^i$ of the current system induced in the latter is also dipole in character, lying in the same plane as $\mathbf{M}_{eq}$ and rotating about the same axis, but displaced by 90° in longitude behind (i.e., to westward) of $\mathbf{M}_{eq}$. The cosmic-ray data indicate that $\mathbf{M}_{eq}{}^i\sim\mathbf{M}_{eq}$, which seems reasonable in terms of the properties of interplanetary matter. The power required to maintain $\mathbf{M}_{eq}{}^i$ is approximately 2×10^{19} erg/sec, and may contribute to the lengthening of the day.

W3. Rapid Decrease of Cosmic-Ray Intensity. R. A. R. PALMEIRA, R. A. D'ARCY, AND R. W. WILLIAMS, *M.I.T.*—The magnetic storm and auroral display of February 10, 1958, was accompanied by a Forbush-type decrease in cosmic-ray intensity of unusual abruptness. We have studied this event with a high counting-rate, high time-resolution telescope consisting essentially of two layers of plastic scintillator, each 6.5 m² in area, with a recording device which gives the number of counts in each 30-sec interval; the counting rate is about 640 per sec. The abrupt drop in intensity began at (0245±5) U.T. on 11 February, about one hour after the start of the aurora and the storm. The intensity dropped 2.1% in about one hour, leveling off at (0340±5) U.T. There was a drop of about 0.5% in intensity during the two hours preceding the sudden drop. After the drop the intensity returned to its pre-drop value in about 13 hr. A second completely independent telescope of 3.25 m² area showed qualitatively similar features on a counting-rate meter. The existence of such sharp decreases in the meson component at sea level puts a severe limitation on theories of the Forbush decreases.[1,2] The postulated transient magnetic fields must be either very large or highly organized.

[1] P. Morrison, Phys. Rev. 101, 1397 (1956).
[2] E. N. Parker, Phys. Rev. 103, 1518 (1956).

W4. Long-Term Temporal Variations of the Primary Cosmic Radiation.* FRANK B. MCDONALD, *State University of Iowa.*—A series of five Skyhook balloon flights have been made in the period 1955–1958 to study long-term temporal variations of the primary cosmic-ray proton and alpha-particle fluxes and energy spectra. These flights were made near a geomagnetic latitude of 55°N. Identical detectors consisting of a Čerenkov counter and a crystal scintillation counter were used on all flights as has been previously discussed.[1] This method offers excellent charge resolution and furnishes a direct determination of the energy spectrum for a given charge component in the kinetic energy interval 150–800 Mev nucleon. Significant changes in the fluxes and energy spectra of protons and alpha particles have been observed during the three-year period. A discussion of these changes will be presented.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] F. B. McDonald, Phys. Rev. 107, 1386 (1957).

W5. Variations in the Cosmic-Ray Neutron Intensity from 1954 to 1957.* JOHN A. LOCKWOOD, *University of New Hampshire.*—From July, 1954, to December, 1957, the monthly mean intensity of the nucleonic component of cosmic radiation measured at Mt. Washington, New Hampshire, geographic latitude 44.2°N, and elevation 6262 ft, decreased by 22%. The decreased intensity now prevailing came about through a series of sudden decreases, the largest occurring in February, 1956, November, 1956, January, 1957, and September, 1957, from which the intensity has only partially recovered. This long term variation has been accompanied by increased intensity changes from day to day. A preliminary study has been made of the largest Forbush type decreases in this period and the results indicate that these decreases do not have a similar time dependence nor do the resulting minima in intensity occur with a regular periodicity. The maximum rate of decrease in some instances is ~2.5% hr^{-1} and the time for the decrease to take place varies from 8 hours to several days. The relationship of geomagnetic disturbances to these decreases has been noted. Such large decreases interfere with the study of any regular periodicity in cosmic-ray intensity which may be present.

* Supported by the Geophysics Directorate, Air Force Cambridge Research Center.

W6. Change in Sea-Level Cosmic-Ray Intensity between 1954 and 1957. A. G. FENTON* AND D. C. ROSE, *National Research Council, Ottawa.*—Data obtained from neutron monitors and meson telescopes at Ottawa (geomagnetic latitude 57°N) and Resolute Bay (geomagnetic latitude 83°N)

will be discussed. During 1954–1957, a period of increasing solar activity, the sea level meson intensity decreased by about 5% at these stations, while the intensity of the nucleonic component decreased by more than 20%. An investigation of the relative response of the two types of recorder to transient decreases during this period indicates that the long-term change in the intensity level cannot be explained entirely in terms of shorter transient decreases, which become more frequent at times of high solar activity. It is suggested that the over-all intensity change is due to the superposition of more than one modulation process, each ultimately controlled by the general level of solar activity. Significant differences are found between the transient decreases observed at the two stations, and these are interpreted as due to a varying energy dependence from one decrease to another, and to anisotropy in the cosmic radiation at these times.

* On study leave from the University of Tasmania, Australia.

W7. Energy Spectrum and Intensity of Alpha Particles at Sunspot Maximum. P. S. FREIER, E. P. NEY, AND C. J. WADDINGTON, *University of Minnesota*.—As part of the IGY program we have continued our series of monitoring measurements on the primary alpha particles of the cosmic rays. Using a stack of photographic emulsions flown on August 31, 1957, we have again observed that the flux is approximately half that previously observed at sunspot minimum, confirming the result reported previously.[1] By making measurements of the multiple scattering we have extended our knowledge of the energy spectrum up to 1.5 Bev/nucleon. Over this range of energies this spectrum is essentially similar to that observed previously, showing that the particles missing at this time have an energy spectrum closely similar to those remaining. In addition, the number of heavier primary particles we have observed indicates that the flux of these has been reduced by approximately the same factor as the alpha particles.

[1] P. S. Freier and E. P. Ney, Nature (to be published).

W8. Changes of the Primary α-Particle Flux of Cosmic Radiation during High Solar Activity.* PETER MEYER, *The University of Chicago*.—During the months of August and September, 1957, the flux of the primary α-particle component was measured at the northern magnetic latitude of 61°. This report is based on two flights which followed the sharp decrease of total cosmic-ray intensity on August 30, 1957. It was found that from flight to flight the average proton and α-particle intensities undergo changes consistent with the concept that a common modulating mechanism is operating on both primary components. For each flight a detailed study of the intensity-time variations within the eight hours of observation reveals a large change in the α-particle flux not accompanied by a comparable variation in the proton intensity. We tentatively ascribe this to an anisotropy in the α-particle flux. Such an independent variation is not a consequence of any modulating mechanism so far considered.

* Assisted in part by the U. S. Committee for the I.G.Y. and the Office of Scientific Research, A.R.D.C., U. S. Air Force.

W9. Cosmic-Ray Decrease as Observed at High Altitude.* KINSEY A. ANDERSON, *University of Iowa*.—During a high-altitude balloon flight made on August 29–30, 1957 from Fort Churchill, Canada, a quite abrupt decrease in the counting rate of the threefold counter telescope was encountered at about 2050 U.T. Ground-level neutron monitors showed this decrease which became 10% after about six hours at Fort Churchill. This decrease is probably to be associated with the solar flare of importance 3+ that occurred on August 28 at 0913 U.T. and the subsequent geomagnetic storm of great intensity in the auroral zone that began at 1920 U.T. on August 29. Comparing the size of the decrease in the counter telescope and neutron monitor at the same time it is found that the high altitude detector shows changes about 75% larger than the ground-level measurements. Of more interest is the fact that at high altitude an initial abrupt decrease is found which is not reflected in the neutron monitor. From about 2130 the telescope counting rate declines in the same manner as on the ground. Such behavior, which strongly suggests modulation of the cosmic-ray beam imposed locally, can be interpreted on Morrisons[1] picture of Forbush decreases if one assumes that some low-energy (<2-Bev) primaries were present.

* Assisted by the IGY program of the National Academy of Sciences. The Office of Naval Research contributed nonfinancial support.
[1] P. Morrison, Phys. Rev. 101, 1397 (1956).

W10. Effect of Combined Magnetic Dipole and Quadrupole Fields on Cosmic Rays. MELVIN SCHWARTZ, *University of Minnesota*.—Recent experiments have indicated that the earth's dipole field alone is insufficient to account for geomagnetic effects on cosmic rays. One is therefore led to examine the effect of a quadrupole field. All the quadrupole terms are considered. It will be shown that one still obtains allowed and forbidden regions as in the dipole case; and that for critical values of a path dependent parameter, the allowed regions separate into two disjoint parts. Thus one still has a simple Stormer cutoff. An intuitively plausible approximation is made for a path dependent integral, thus yielding an analytical expression for the cutoff rigidity at latitudes up to about 30° geomagnetic. The resulting expression indicates a longitude dependent shift in the latitude of minimum cosmic-ray intensity. However the shift indicated by the approximation is too small (although in the right direction) to account for the recent experiments of Rothwell and Quenby and Simpson *et al.*[1] which indicate that the cosmic ray "equator" tends to coincide with the magnetic dip "equator."

[1] Rothwell, Quenby, and Simpson *et al.*, *Proceedings of the Varrenna Conference on Cosmic Rays* (to be published).

W11. Cosmogenic Helium Distribution in the Grant and Carbo Meteorites.* JOHN H. HOFFMAN AND A. O. NIER, *University of Minnesota*.—The half-ton iron meteorite, Grant, has been cut† in a manner similar to Carbo,[1] and the cosmogenic He^3 and He^4 contents were measured using a double-focusing mass spectrometer. Contours of constant He^3 and He^4 have been plotted for a cross section of each of the meteorites. The total helium content per gram of Grant decreases monotonically toward the center, as in Carbo, but has an absolute value approximately 30% higher. Whereas the He^3/He^4 ratio in Carbo has an approximately constant value of 0.24 it decreases monotonically from 0.30 to 0.26 between the surface and center of Grant. Thus the transition effect of the depth variation in Carbo reported by Paneth *et al.*[2] does not appear to exist in either meteorite. A comparison is made between the present results and computations assuming an omni-directional cosmic-ray flux acting on regular shaped bodies of various sizes.

* Research supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Samples obtained through the cooperation of Dr. E. P. Henderson, U. S. National Museum, Washington, D. C.
[1] John H. Hoffman and A. O. Nier, Bull. Am. Phys. Soc. Ser. II, 2, 349 (1957).
[2] Paneth, Reasbeck, and Mayne, Nature 172, 200 (1953).

W12. Rare Gases in Meteorite Carbo and a Cu Target Exposed to 6.2-Bev Protons.* RUDOLF H. BIERI,† *University of Minnesota*.—A mass spectroscopic analysis of the rare gases He^3, He^4, Ne^{20}, Ne^{21}, Ne^{22}, A^{36}, and A^{38} was made in the meteorite Carbo at different depths. Within the accuracy of the measurements, no change of isotopic or elemental ratios could be found. An analog set of isotopes as above was also analyzed in the copper target but with the addition of the

TABLE I.

	A^{37}/Ne^{21}	He^3/Ne^{21}	He^3/A^{37}	He^3/He^4
Meteorite Carbo	5.1	98	19	0.244
Cu target, 6.2 Bev	1.9	24	13	0.171

radioactive isotopes A^{37}, A^{39}, and A^{42}. A comparison of these two sets of measurements shows good agreement between the ratios He^3/He^4 and He^3/A^{37} when a decay correction[1] for tritium is applied, while the ratios A^{37}/Ne^{21} and He^3/Ne^{21} differ both by a factor of 2.8. Some of the original ratios are shown in Table I.

* Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† Now with Midwestern Universities Research Association.

[1] O. A. Schaeffer and J. Zähringer (private communication).

W13. X-Rays from Visible Aurorae at Minneapolis. J. R. WINCKLER, L. PETERSON, R. ARNOLDY, AND R. HOFFMAN, *University of Minnesota.**—During three auroral storms on June 30–July 1, September 12–13, and September 22–23, 1957, we have observed bursts of x-rays during balloon flights at 10 g/cm² depth in the atmosphere over Minneapolis. The x-rays have an energy of from 50 to 100 kev, an integrated intensity from 0.03 to 0.14 mr, and a maximum measured peak intensity of 0.4 mr/hr. One burst was observed at 47 g/cm² atmospheric depth (70 000 ft), and we estimate that above the atmosphere this may have corresponded to 500 mr/hr for at least 10 min. The current of high-energy electrons is at least 3×10^6 electrons/cm² sec, and probably an order of magnitude greater, and is therefore approximately equal to auroral proton fluxes, and to the fluxes observed in soft radiation at rocket heights. The x-ray bursts usually appear when a homogeneous auroral arc develops a strong ray structure, or when rays increase in intensity. The inferred energy and high velocity of the primary auroral electrons necessitates an acceleration mechanism near the earth to avoid contradictions with the commonly accepted sun-earth transit times for corpuscular beams.

* This research sponsored by the U. S. National Committee for the International Geophysical Year through the National Science Foundation. Program assisted by the Office of Naval Research.

W14. Atmospheric and Interplanetary Hydrogen. J. E. KUPPERIAN, JR., E. T. BYRAM, T. A. CHUBB, AND H. FRIEDMAN, *U. S. Naval Research Laboratory.*—The directional intensity of the Lyman-α radiation of hydrogen has been measured in the night sky by means of rocket-borne nitric oxide ion chambers.[1] The results of this survey reveal two sources of L_α radiation, an extraterrestrial source (3.2×10^{-3} erg/cm² sec sterad) and an atmospheric source (1.36×10^{-3} erg/cm² sec sterad). These sources are interpreted as solar L_α resonantly scattered by interplanetary atomic hydrogen which in turn is scattered by atomic hydrogen in the D and E layers of the earth's atmosphere. Density calculations are handicapped by our lack of knowledge of the solar L_α profile. A preliminary estimate will be discussed using the earth's atmospheric hydrogen as a scattering analyzer of the direct solar L_α flux.

[1] Kupperian, Byram, Chubb, and Friedman, Ann. géophys. (to be published).

W15. Interplanetary Dust Distribution. DAVID B. BEARD, *Lockheed Aircraft Corporation.*—Measurements of zodiacal light have been reinterpreted to give distributions of interplanetary dust as the dust density falls off inversely with increasing power of its distance from the sun. In particular, seasonal fluctuations of zodiacal light intensity and local increases of intensity such as the backward scattering in the gegenschein have been reinterpreted in terms of a localized increase in dust density around the earth due to the influence of the earth's gravitational field. This concentration is crudely estimated from the zodiacal light data and reasonable estimates of the dust velocity and direction. Since the over-all dust distribution is the result of (1) the Poynting-Robertson spiraling in of the dust caused by the relativistic interaction of the dust with the sun's radiation, (2) the distribution of the source of the dust, (3) the ellipticity of the orbits of the dust, and (4) the disappearance of the dust caused by evaporation, sputtering, planet capture, and radiation pressure, reliable estimates of its distribution in space distinguishes the relative importance of these processes from one another and indicates the orbit ellipticity and therefore the velocity of the dust relative to the earth. Preliminary estimates based primarily on Whipple's studies of comets and meteors will be presented.

SATURDAY AFTERNOON AT 1:30

Sheraton-Park, Exhibit Room

(D. C. PEASLEE presiding)

Theoretical Physics V; Nuclear Theory

WA1. Polarization of the Proton from Photodisintegration.* MASAAKI KAWAGUCHI, *Purdue University.*—The transverse polarization of the outgoing proton from photodisintegration of the deuteron is calculated by partial wave analysis. General formulas for the polarization as well as for the angular distribution are given in terms of the Racah coefficients. Some numerical values for polarization are given for low-energy phenomena, where ^1S and ^3P states are dominant. When the angular distribution is written as a $+b\sin^2\theta$, the polarization is a function of a, b, and the nucleon-nucleon scattering phase shifts of S and P states. At 90 degrees in the center-of-mass system, for instance, only $^1S_0$ and $^3P_1$ contribute to the polarization, and 20 to 30% polarization is expected for 20- to 40-Mev gamma rays. For higher energies the electric quadrupole radiation is also taken into account.

* Assisted by contracts with the Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.

WA2. Study of the Triton Wave Function Based on Stripping Reactions.* A. I. HAMBURGER AND E. W. HAMBURGER, *University of Pittsburgh.*—The ratio of the cross sections of (d,p) and (d,t) reactions between the same energy levels gives information about the triton wave function, namely the probability $|A_0|^2$ that the triton can be described as a deuteron plus a neutron.[1] The experimental data give the value of $|A_0|^2C_T^2$, where C_T is a normalization constant. The result for the $Li^6(d,p)Li^7$, $Li^7(d,t)Li^6$ reactions,[2] compared

for the same values of the transfer momentum, is $|A_0|^2C_T^2 = 1.3\times10^{13}$ cm^{-1}. The $C^{12}\rightarrow C^{13}$ case was recalculated,[3] giving $|A_0|^2C_T^2 = 0.5\times10^{13}$ cm^{-1}. In the lithium case the same radius was used for (d,p) and (d,t); these angular distributions are better fitted by the stripping curves than the carbon ones.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of Naval Research and the U. S. Atomic Energy Commission.
[1] S. T. Butler and E. E. Salpeter, Phys. Rev. **88**, 133 (1952).
[2] Levine, Bener, and McGruer, Phys. Rev. **97**, 1249 (1955).
[3] A. Werner, Nuclear Phys. **1**, 9 (1956) finds $|A_0|^2C_T^2 = 1.8$.

WA3. Boundary Effects in Deuteron Stripping on Spheroidal Nuclei.* J. SAWICKI, *Princeton University.*—Recently the theory of deuteron stripping on spheroidal nuclei has been developed using the unified nuclear model.[1,2] S. G. Nilsson's strong coupling wave functions representing the captured neutron in a (d,p) reaction allow natural mixing of two or more l values and produce characteristic selection rules and branching ratios given by the neutron reduced widths. There are additional contributions to such a reaction amplitude coming from the geometrical effect of the spheroidal shape. The usual stripping boundary conditions are assumed at a spheroidal boundary rather than at a spherical Butler radius r_0. The resulting contributions correspond to a number of different angular momenta L, in general. They do not violate the strong coupling selection rule $K_f = K_i + \Omega_n$. The contributions of $L=0$ can occur only if $|\Omega_n| = \frac{1}{2}$. These shape contributions are, in general, rather small; they give, however, a background which renders it hard to analyze quantitatively various possible configuration mixing effects.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] J. Sawicki, Nuclear Phys. (to be published).
[2] G. R. Satchler, Ann. Phys. (to be published).

WA4. Stripping Nucleons from the *D-D* Reaction (6–14 Mev).* JAMES E. YOUNG, *Los Alamos Scientific Laboratory.*—Preliminary to computation of the T matrix for stripping, this for the reaction D-D producing polarized nucleons, we have computed the elastic cross section for hard-sphere deuteron scattering in the initial state. The point of view is taken that initial and final state amplitudes which contribute to the stripping matrix element are to be normalized by *fitting* the corresponding elastic scattering distributions. In this way a check is obtained on the validity of collision matrices which occur in the theory. Since we can *calculate* the reduced widths (these from known ground-state wave functions) in the particular problen under investigation, a large amount of arbitrariness in the theory is removed. While the cutoff radius for nucleon capture into the ground state of the residual nucleus is still an adjustable parameter, there is no logical necessity for introducing normalization factors into the fits for the stripping cross sections. Our computations,[1] still incomplete, describe $D(d,n)He^3D(d,p)T$ for 6–14 Mev deuterons. Ultimately they will give estimates of the polarization distributions for emitted nucleons.

* Work supported under auspices of the U. S. Atomic Energy Commission.
[1] J. E. Young, Bull. Am. Phys. Soc. Ser. II, **2**, 381 (1957).

WA5. Optical-Model Calculations for the Deuteron Pickup Process.* KENNETH R. GREIDER, *University of California, Berkeley.*—The deuteron-pickup process has been reinvestigated in an optical-model approximation. The original Chew-Goldberger theory[1] has been modified to include the interaction of the incoming nucleon with the entire target nucleus and the interaction of the outgoing deuteron with the residual nucleus, by means of a smoothly varying optical potential. This calculation gives a broader angular distribution and a smaller forward amplitude than the Born-approximation treatment. By fitting the theory with experimental cross sections for carbon, one requires a nuclear momentum density distribution in the range from $\exp(-E/13)$ to $\exp(-E/20)$.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] G. F. Chew and M. L. Goldberger, Phys. Rev. **77**, 470 (1950).

WA6. Low-Lying 0^+ State in $_{14}Si_{16}^{30}$.* R. D. LAWSON, *University of Chicago.*—According to the shell model the ground-state configuration of the last two neutrons in Si^{30} should be $(2s_{\frac{1}{2}})^2$. A possible low-lying 0^+ state in this nucleus arises if both neutrons are excited to the $1d_{\frac{3}{2}}$ level and couple their spins to zero. From the data on binding energies one can deduce that the pairing energy associated with $(2s_{\frac{1}{2}})^2$ is 2.14 Mev and with $(1d_{\frac{3}{2}})^2$ is 2.74 Mev. The data on Si^{30} indicate that the $1d_{\frac{3}{2}}$ level lies approximately 1.3 Mev above the $2s_{\frac{1}{2}}$ state. Thus one expects an excited $J=0$ state in Si^{30} to lie at about 2 Mev. The lowest known levels in this nucleus lie at 2.24 Mev and 3.51 Mev, and both are observed to gamma decay to ground showing neither of these can be the predicted 0^+ state. In addition there are no low-energy gammas observed which do not fit into the proposed level scheme,[1] indicating that the predicted state lies below the 2.24-Mev level and is the first excited state of the nucleus. The relationship of these considerations to levels observed in neighboring nuclei will be discussed and indicates that the picture presented above is consistent.

* Work supported by the U. S. Atomic Energy Commission.
[1] P. M. Endt and C. M. Braams, Revs. Modern Phys. **29**, 683 (1957).

WA7. Elastic Scattering of N^{14} by N^{14}.* J. E. TURNER, J. S. MCINTOSH, AND S. C. PARK, *Yale University.*—The analysis[1] of N^{14}, N^{14} elastic scattering experiments[1] in terms of Blair's model[2] of α-particle scattering gave good reproduction of the data provided the large nuclear radius 1.66×10^{-13} A[3] cm was used. A re-examination of the data employing Coulomb functions, a transition density region for nuclear matter, and the unitary property of the scattering matrix[3] gave other possible fits to data which do not depend on the drastic assumptions needed with Blair's model. Some of these fits are better than those obtained by Blair's method and the effective nuclear absorption works out reasonably for high L, while for low L the assumption of complete absorption fits best. A unique interpretation is difficult.

* This research was supported by the U. S. Atomic Energy Commission and by the Office of Ordnance Research.
[1] H. L. Reynolds and A. Zucker, Phys. Rev. **102**, 1378 (1956).
[2] J. S. Blair, Phys. Rev. **95**, 1218 (1954).
[3] This approach was suggested by G. Breit.

WA8. Interpretation of the Inelastic Scattering of Alpha Particles by Be^9.* W. T. PINKSTON, *Princeton University.*—The spectrum of the alpha particles inelastically scattered from Be^9 shows two pronounced peaks, corresponding to excitation of the 2.428-Mev and the 6.8-Mev levels. In particular there is no peak corresponding to the 3.1-Mev level. Blair and Henley have calculated the differential cross sections for these processes in impulse approximation in terms of the alpha-particle model of Be^9. In this model the 2.428- and 6.8-Mev levels are the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ members of the lowest $(K=\frac{1}{2}^-)$ rotational band and are strongly excited by alphas, whereas the 3.1-Mev level corresponds to a particle excitation, which should be weaker. We have calculated these cross sections on the shell model in Born approximation with zero-range forces. Probable spin assignments of $\frac{1}{2}^-$, $\frac{1}{2}^-$, and $\frac{3}{2}^-$, in that order, have been assumed for the above-mentioned excited states. In jj coupling the $\frac{1}{2}^-$ level should show up with about $\frac{1}{4}$ the intensity of the $\frac{1}{2}^-$ level, whereas the $\frac{3}{2}^-$ should be much weaker. The results of intermediate coupling theory will also be presented.

* This work was supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

WA9. Collective and Interparticle Interactions in Even-Even Nuclei.* B. JAMES RAZ,† *Argonne National Laboratory.*—A calculation using two equivalent $f_{7/2}$ particles and adding surface effects to the two-body intraction will be reported on. The effects of increasing the strength of (a) the surface interaction, and (b) the two-particle interaction are computed. Some of the qualitative regularities observed in even-even nuclei in the so-called vibrational region are obtained and the agreement is somewhat better than that with a pure vibrational spectrum.[1] In contrast to earlier calculations these results give a spin of 2^+ for the second excited state, as observed. The form and strength used for the two-body interaction is $H_{12}=3\hbar\omega[3-\sigma_1\cdot\sigma_2]\exp(-r^2/r_0^2)$ with $r_0\sim 2.7\times 10^{-13}$ cm. The appropriate values of the deformation parameter x are less than 0.7.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Department of Physics, Carleton College, Northfield, Minnesota.
[1] See for example Alder, Bohr, Huus, Mottelson, and Winther, Revs. Modern Phys. **28**, 432 (1956).

WA10. Low-Energy Excitations of Even-Even Nuclei. C. DE DOMINICIS, *Centre d'Etudes Nucleaires de Saclay,* AND P. C. MARTIN, *Harvard University.*—It has been pointed out by Bohr, Mottelson, and Pines that the first excited levels in even-even nuclei which are not collective in nature, are generally 1 Mev above the ground state even though one one would expect statistically that the level spacing in heavy nuclei should be of the order of 200 kev. That the energy gap might be explained in terms of a phenomenon similar to that occurring in superconductivity was therefore proposed by these authors. This proposal appears plausible in view of the prediction of a similar gap between the single particle excitations and the ground state in a simple model of superconductivity proposed by Bardeen, Cooper, and Schrieffer. It is possible to demonstrate that the existence of a gap depends solely on the attractive nature of the interaction between fermions. The size of the gap may be related to a pole in the two particle time-dependent correlation function of the many-fermion system. This correlation function may actually be calculated for factorizable potentials which fit the observed nuclear data. We have performed approximate calculations for two factorizable potentials and found energy gaps of a size compatible with experiment, but so sensitively dependent on the potential that definitive results cannot be stated.

WA11. Hydrodynamic Calculation of Spontaneous Fission Lifetime for Mendelevium. W. D. FOLAND AND R. D. PRESENT, *The University of Tennessee.*—Attempts[1] have been made to calculate spontaneous fission lifetimes from the liquid-drop model in which the Gamow integral over the nucleon coordinates is transformed into an integral over the deformation parameters a_n of the drop (whose surface is given by $r=R\,\Sigma a_n P_n(\cos\theta)$). This transformation requires evaluation of the kinetic energy in terms of a_n and $\dot{a}_n$. Assuming irrotational motion, which corresponds to a minimum Gamow integral, the velocity potential is expanded in zonal harmonics and the coefficients are related to the a_n and $\dot{a}_n$. Previous calculations[1] have been incomplete. For elements sufficiently close to instability, series expansions for the kinetic and potential energies can be used. We have neglected all parameters but a_2 and carried the hydrodynamic calculations through terms in a_2^4. Because of uncertainties in nuclear constants, the value of x, which determines the potential barrier, is chosen to give a barrier height agreeing with extrapolations of empirical activation energies ($2x$=electrostatic energy/surface energy of undeformed drop). The resulting values of the Mv lifetime range from 10^{-1} to 10^3 sec due to calculational uncertainties; the experimental value is 3.5 hr.

[1] Present, Reines, and Knipp, Phys. Rev. **70**, 557 (1946); S. Frankel and N. Metropolis, Phys. Rev. **72**, 914 (1947).

WA12. Correlations and the Nuclear Magnetic Moment.* R. D. AMADO, *University of Pennsylvania.*—Correlation structure can be introduced into the shell model as a product of pair correlation functions each of which vanishes within the repulsive core radius and then approaches one with a short range dependent only on the Fermi momentum and relative energy of the pair. Correlations of this type are independent of the state of a particle within a given orbit. The additional affect of such scalar, state-independent correlations on the magnetic moment of a closed shell plus one nucleus vanishes leaving only the shell model value. This vanishing can be extended to correlations having a scalar spin dependence and to certain more complicated symmetries. The effect of residual state dependent correlations is estimated to give for O^{17} a correction to the magnetic moment of $+0.002$ magneton. There is no modification to the magnetic moment operator due to velocity dependence of the correlation functions, and the expectation value of the space exchange moment coming from the exchange part of the attraction in the Hamiltonian is the same as given by the shell model.

* Supported in part by The National Science Foundation.

WA13. Neutron Strength Functions and Effective Nuclear Radii.* KAMAL K. SETH, *Duke University.*—An improved method has been developed for the analysis of transmission data for unresolved resonances in light nuclei in the kev region of neutron energies, in order to determine the s-wave strength function,[1,2] $(\bar{\Gamma}_n^0/\bar{D})$ and the effective nuclear radius, R'. The method is based on the use of transmission data for two different sample thicknesses, and the equation, $\bar{\sigma}_t=4\pi(R')^2+2\pi^2\lambda^2(\Gamma_n/D)-\pi^2\lambda^2(\bar{\Gamma}_n/D)^2$. It is shown that the last term, being energy indepeudent and therefore indistinguishable from the potential scattering term $4\pi(R')^2$ cannot be neglected for light nuclei. Since $|4\pi(R')^2-\pi^2\lambda^2(\Gamma_n/D)^2|$ may be negative for a particular case, the neglect of the second term yields thick and thin sample results in absolute disagreement with each other. Taking proper account of this term and beam hardening, we have analyzed the data[1] from this laboratory for a number of light nuclei for both $(\bar{\Gamma}_n^0/\bar{D})$ and R' and find very good agreement between the thin and thick sample values. These results are presented and their interpretation in the light of current optical model theory discussed. It is suggested that the data indicate existence of nuclear deformations for neutron number $28\leqslant N\leqslant 50$.

* Supported by the U. S. Atomic Energy Commission.
[1] H. Marshak and H. W. Newson, Phys. Rev. **106**, 110 (1957).
[2] R. G. Thomas, Phys. Rev. **98**, 77 (1954).

WA14. Influence of a Nuclear "Pear-Shape" on Neutron Scattering. KIRK W. MCVOY,* *Brookhaven National Laboratory.*—In the original Feshbach-Porter-Weisskopf model of neutron scattering, the target nucleus was represented by a spherical potential well. Recent calculations[1] have shown the strength function (Γ_n/D) to be sensitive to quadrupole deviations from the spherical shape, and their inclusion improves the fit to experimental data in the rare-earth region. These calculations have been extended to include a possible octupole ("pear-shaped") deformation of the nucleus, $R(\theta)=R_0[1+aP_2(\cos\theta)+bP_3(\cos\theta)]$, the occurrence of which has been suggested for nuclei in the region $A\sim 235$. The experimental neutron data for these nuclei are definitely incompatible with a spherical shape, $a=b=0$; for the choice of square-well parameters $V_0=42$ Mev, $\xi=0.03$, $r_0=1.45f$, they are compatible with $a=0.15$, $b=0$, and put an upper limit of $b\leq 0.03$ on b. This limit is sensitive to the values of r_0 and V_0, and could be relaxed by using a smaller r_0.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] B. Margolis and E. S. Troubetzkoy, Phys. Rev. **106**, 105 (1957); Chase, Wilets, and Edmonds (to be published).

SATURDAY AFTERNOON AT 1:45

Sheraton-Park, Burgundy Room

(E. S. AMBLER presiding)

Cryogenics

X1. Absorption of Sound in Liquid Helium below 0.6°K. K. DRANSFELD, *Bell Telephone Laboratories.*—A tentative explanation is given for the sound absorption observed in He II in the phonon region below 0.6°K, arising from a three-particle interaction between acoustic phonons and thermal phonons. This interaction occurs only when the acoustic and thermal phonons are traveling in nearly the same direction, and leads to a "bunching" of the thermal phonons. The sound absorption predicted by this theory is of the observed magnitude and varies with temperature, frequency, and pressure in agreement with the measured data.[1-3] When the mean free path of the thermal phonons is reduced, for instance, by adding ^{3}He, the absorption is expected to decrease.

[1] C. E. Chase, Am. J. Phys. **24**, 136 (1956).
[2] Newell and Wilkes, Phil. Mag. **1**, 588 (1956).
[3] W. M. Whitney, Phys. Rev. **105**, 38 (1957).

X2. Interaction between First and Second Sound in Liquid Helium. A. J. DESSLER, *Lockheed Missile Systems.*—The reflection coefficient for second sound reflected by first sound is derived. This type of reflection is unique in that the discontinuity (the first sound wave) travels faster than the wave being reflected. Hence, the discontinuity can overtake the second sound wave from behind. It is shown that the principal term in the reflection coefficient is due to the particle velocity (v_p) associated with a pressure wave: $v_p=\Delta p/\rho c_1$. The reflection coefficient is given by $r=\pm\Delta\rho c_1/2\rho c_2$ where the + sign refers to the case where the discontinuity overtakes the second sound wave from behind while the − sign refers to the case of a head-on collison.

X3. Velocity of Second Sound in He^3-He^4 Mixtures under Pressure.* S. D. ELLIOTT, JR., AND HENRY A. FAIRBANK, *Yale University.*—Measurements of second sound velocities in superfluid He^3-He^4 mixtures under saturated vapor pressure have been extended to concentrations as high as 63.9 mole percent He^3 and temperatures down to 0.2°K. From these data the variation of the lambda transition temperature with He^3 concentration has been determined and observations have been made on the single-phase two-phase transition which takes place in these mixtures below 1°K.[1] The apparatus has recently been modified to permit similar measurements to be made under pressure up to the melting pressures for the respective mixtures. Preliminary observations, made with a mixture containing 30.4% He^3 at pressures up to 11.4 atmos, show a progressive reduction of the second sound velocity, while the lambda transition temperature falls with increasing pressure in an approximately linear fashion with a slope of −0.013°K/atmos.

* Assisted by the National Science Foundation and the Office of Ordnance Research.
[1] G. K. Walters and W. M. Fairbank, Phys. Rev. **103**, 262 (1956).

X4. Energy-Momentum Relation in Liquid Helium by Inelastic Scattering of Neutrons. D. G. HENSHAW, *Chalk River Laboratories.*—The wavelength change of neutrons scattered from liquid helium has been measured at 4 angles in the range 35° to 90°. At the lowest liquid temperature, the broadening of the spectrum is <0.5°K. These measurements have been made using two instruments. In one the wavelength shift of the beryllium "edge" of neutrons scattered from liquid helium using the Chalk River Chopper gave $Q=1.16$ and 2.14 A^{-1} corresponding to $\Delta E=13.8$ and 10.9°K. In the other the shift of monochromatic neutrons produced by the rotating crystal apparatus[1] gave $Q=0.86$ and 1.87 A^{-1} corresponding to $\Delta E=13.1$ and 8.3°K, respectively. Also with this latter instrument the temperature variation of the wavelength distribution of scattered neutrons has been measured at 80° using 4.15 A neutrons. The distribution broadens and becomes asymmetrical and the position of the maximum shifts to small wavelengths with increasing temperature even for temperatures below the λ point. The full width at half-maximum is <0.5°K, ~11°K, and ~20°K corresponding to liquid temperatures of 1.27°K, 2.08°K, and 4.21°K, respectively. The measurements at the lowest liquid temperature give directly[2] the energy-momentum relation which may be compared to that proposed by Landau.[3]

[1] B. N. Brockhouse, Bull. Am. Phys. Soc. Ser. II, **3**, 233 (1958).
[2] M. Cohen and R. P. Feynman, Phys. Rev. **107**, 13 (1957).
[3] L. Landau, J. Phys. (U.S.S.R.) **5**, 71 (1941); **11**, 91 (1947).

X5. Range of Order of Superconducting Electrons in Normal Conducting Barriers.* HANS MEISSNER, *The Johns Hopkins University.*—It has been found earlier that an interposed normal conducting barrier does not necessarily prevent the superconductivity of a contact between two superconducting wires.[1] This has been explained by the assumption that the number of superconducting electrons in the normal conducting barrier decreases relatively slowly with distance from the superconductor. The observation of the barrier thickness at which superconductivity disappears provides therefore a means of measuring the "range of order" of the superconducting electrons. Previous measurements on copper-plated tin (Sn) wires[1] have now been extended to nickel- and gold-plated tin wires. Experiments with other barrier materials are in progress. While gold, similar to copper, allows superconductivity up to thicknesses of 1000 to 2000 A, nickel quenches superconductivity already at a thickness of 100 A. This might be due to the fact that the saturation magnetization of the nickel film becomes at about 75 A large enough to quench superconductivity in the neighborhood of the contact. One contact with gold barriers showed a behavior as if there were another transition temperature above 3.72°K. This suggests that one of the gold-tin compounds may have a rather high transition temperature. (See the observations on Sn-In contacts in reference 1.)

* Work performed under contract with the Office of Naval Research.
[1] Hans Meissner, Phys. Rev. **109**, 668 (1958).

X6. Ultrasonic Attenuation in Superconductors: Dependence on Electron Mean Free Path.* H. V. BOHM AND R. W. MORSE, *Brown University.*—When the electron mean free path (l) is long compared to the ultrasonic wavelength (λ), i.e., $kl=2\pi l/\lambda>1$, then the attenuation of longitudinal waves by electrons in superconductors can be related simply to the superconducting energy-gap of the theory of Bardeen, Cooper, and Schrieffer.[1] We report here measurements in superconducting indium which cover the range of both $kl>1$ and $kl<1$. Besides the expected kl dependence of the magnitude of the attenuation, the superconducting attenuation seems to decrease more rapidly below the transition temperature (T_c) the smaller the value of kl when $kl<1$. The frequency dependence, which is square-law for the normal state when $kl<1$, is not radically altered throughout the superconducting range (it actually becomes slightly stronger than square-law). A comparison will also be made with shear waves when $kl>1$. Here the attenuation shows a considerably

more rapid decrease with temperature below T_c than for longitudinal waves of either comparable kl or frequency.

* Supported in part by contract with the U. S. Air Force through the Office of Scientific Research.
[1] R. W. Morse and H. V. Bohm, Phys. Rev. 108, 1094 (1957).

X7. Thermal Conductivity of Tin-Indium Alloys in the Superconducting State. C. A. SHIFFMAN,* *The Clarendon Laboratory, Oxford, England.*—The thermal conductivities of ten specimens of tin with up to 8% indium have been measured from 2 to 20°K. The lattice contribution in the superconducting state, K_{ps}, is derived on the assumption that the conductivity of pure tin is entirely electronic. K_{ps} is found to vary roughly as t^{-2} or t^{-3}, depending on the reduced temperature, t, and the amount of impurity. Below $t=0.8$ K_{ps} shows a sensitive and regular dependence on the indium concentration. These results are discussed in terms of the scattering mechanisms believed to be relevant at these temperatures and the assumptions made in the derivation of K_{ps}.

* Now at the National Bureau of Standards, Washington 25, D. C.

X8. Low-Temperature Thermal Magnetoconductivity in Ferrimagnetic Crystals.* DOANE DOUTHETT AND S. A. FRIEDBERG, *Carnegie Institute of Technology.*—The thermal conductivities of single crystal bars of several ferrites have been measured over the temperature interval 1.5° to 25°K in both zero external magnetic field and in a field of about 10 kilooersted. The zero field conductivities of specimens of manganese ferrite and mixed cobalt-zinc ferrite are quite low, approximately 1.5 mw/cm°K at 4°K. A mixed manganese-zinc ferrite specimen, however, exhibits a much larger zero field conductivity, about 10 mw/cm°K at 4°K. Upon application of a magnetic field parallel to the direction of heat current flow the conductivities of the manganese ferrite and cobalt-zinc ferrite specimens are increased over the whole temperature range. The magnetoconductivities are rather large. For example, $(\Delta K/K_0)\cong 0.2$ for manganese ferrite at 2°K. Such a field produces no noticeable change in the conductivity of the manganese-zinc ferrite. The concentration of free charge carriers in these materials is extremely small at low temperatures suggesting that the mechanism producing the thermal magnetoconductivity is quite different from that in good electrical conductors. A plausible explanation of the sign, magnitude, and temperature dependence of the magnetoconductivity follows from the assumption that the heat current is primarily a phonon current limited by phonon-spin wave scattering. Application of a sufficiently large magnetic field reduces this scattering.

* Work supported in part by the National Science Foundation and the Office of Naval Research.

X9. Magnetic Susceptibility of Synthetic Ruby at Low Temperatures.* K. BRUGGER AND J. G. DAUNT, *The Ohio State University.*—The magnetic susceptibilities of several synthetic rubies, kindly supplied by the Linde Company, have been measured in the liquid helium temperature range. The susceptibility was found to be proportional to the concentration of the Cr ions in Al_2O_3. For a Cr concentration of 0.614% by weight the data could be described by a Curie-Weiss law with $c=7.32\times10^{-4}$ per cm³ and $\Delta=0.2$°K along the principal axis and with $c=7.40\times10^{-4}$ per cm³ and $\Delta=-0.1$°K perpendicular to the principal axis. Measurements of the susceptibility as a function of the angle between the measuring field and the direction of the principal axis were also carried out and it was found that the anisotropy, $2(\chi_{\parallel}-\chi_{\perp})/(\chi_{\parallel}+\chi_{\perp})$, was negligibly small at 4.2°K and amounted to approximately 26.4% at 1.2°K for the specimen with 0.614% Cr.

* Assisted by a contract between the Office of Naval Research and the Ohio State University Research Foundation.

X10. Low-Temperature Thermal Conductivity of Lithium Fluoride Crystal upon Irradiation by Co^{60} Gamma Rays, Fast Neutrons, and Thermal Neutrons. ANNA FONER COHEN AND L. C. TEMPLETON, *Oak Ridge National Laboratory.*—The thermal conductivity κ of LiF single crystals has been measured at low temperatures before and after room temperature exposure to Co^{60} γ rays and to fast neutrons. After exposure marked decreases in κ over the temperature region 3 to ~80°K have been observed. More recently, the low-temperature thermal conductivity of LiF crystal has been measured following successive irradiation to thermal neutrons; and concurrent measurements of the density of the crystal have also been made. Both κ in the low-temperature range and density are observed to decrease monotonically with thermal neutron dose up to an exposure of $\sim5\times10^{17}$ n/cm². Further irradiation to doses ($>1\times10^{18}$ n/cm²) for which a partial density recovery is expected[1] are being carried out. These results will be interpreted in the light of structural changes which have been previously observed for thermal neutron-irradiated LiF.[1]

[1] G. Mayer, *International Conference on the Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955* (United Nations, New York, 1956), Vol. 7, p. 686.

X11. Limiting Form of Equivalent Debye θ Function at 0°K. PAUL M. MARCUS AND ANTHONY KENNEDY, *Carnegie Institute of Technology.*—The equivalent Debye θ function, $\theta_D(T)$, which represents a lattice specific heat, has the limiting form near 0°K, $\theta_D(T)/\theta_D(O)=1-C(T/\theta_D(O))^2$. For cubic crystals $\theta_D(O)=\bar{\theta}_0 I^{\frac{1}{2}}$ where $\bar{\theta}_0$ is a simple function of an elastic modulus, the molecular weight, and the density, but $I=(1/12\pi)\int\int d\Omega\,\Sigma_i v_{ri}^{-3}$ where the relative sound velocity in $d\Omega, v_{ri}=v_i/v_0$; v_0 is a reference velocity and v_i the sound velocity for the ith acoustical mode. I is a function of just two parameters, the ratios of elastic moduli $r_1=(c_{11}-c_{12})/2c_{11}$, $r_2=c_{44}/c_{11}$. I has been computed accurately by direct integration with a digital computer, and tabulated over the interesting ranges of r_1 and r_2. A set of contour curves of constant $I^{-\frac{1}{2}}$ on the r_1,r_2 plane has been prepared which permits direct reading of $I^{-\frac{1}{2}}$ to about 0.2%. The coefficient C, giving the curvature of $\theta_D(T)$ at 0°K depends on the integral of $\Sigma_i b_i/v_{ri}^5$, where $b_i(\theta,\phi)$ is the first dispersion coefficient of the ith mode, defined by $\omega_i(\mathbf{k})=v_i k(1-b_i k^2)$. C can be evaluated by the same integration procedure that gave $\theta_D(O)$, but depends also on the dispersion law. It has been evaluated for several materials using a simple model of the dispersion,[1] and can be readily evaluated for any prescribed force constant model.

[1] P. Marcus and A. Kennedy, Proceedings of the Fifth International Low Temperature Conference, Madison, 1957.

X12. Low-Temperature Breakdown of the Relationship between Lattice Specific Heat of a Metal and Its Elastic Constants.* J. L. WARREN AND R. A. FERRELL, *University of Maryland.*—The low-temperature lattice specific heat is inversely proportional to the mean velocity of sound cubed, and hence is a function of the elastic constants. A lattice vibration changes the Fermi sea from spherical to spheroidal shape. This spheroidal higher energy state of the electron system relaxes via lattice-electron interactions in the same time, τ, which enters in the theory of electrical conduction.[1] Hence there is an extra contribution to the elastic constants for frequencies greater than τ^{-1}. Although at room temperatures τ^{-1} is above the Debye cutoff frequency, because of the T^5 law it becomes much smaller than it near 0°K. At low temperatures the mean velocity of sound should therefore only be computed from unrelaxed elastic constants, which are appreciably stiffer than the experimentally determined relaxed static constants. Consequently the Debye Θ deduced from specific heat measurements should be larger than the value computed from the static constants.

* Research supported by the Office of Naval Research.
[1] R. W. Morse, Phys. Rev. 97, 1716 (1955).

SATURDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(A. ZUCKER presiding)

Nuclear Reactions IV, Including Fission

XA1. Modifications of the Proton-Proton Chain. A. G. W. CAMERON, *Atomic Energy of Canada Limited.*—The unexpectedly large cross section measured[1] for the $He^3(\alpha,\beta)Be^7$ reaction implies that this reaction will complete the proton-proton chain in stars with higher temperatures and helium concentrations, supplanting the $He^3(He^3,2p)He^4$ reaction. The energy generation rate is thus doubled because of the more efficient conversion of hydrogen into helium. From recent solar model calculations[2] it appears that the $He^3(\alpha,\gamma)Be^7$ process did not take place in the primordial sun, but now predominates within about the central seven percent of the radius. Be^7 is ionized in the solar interior. The free electron capture rate has been estimated by replacing the wave function for a K electron at the nuclear surface by that for a free electron. This rate appears to be slightly smaller at the solar center than the rate for the $Be^7(p,\gamma)B^8$ process, which has been computed for direct nonresonant capture using a square well. If this is correct, then the very energetic B^8 neutrinos should have a flux at the earth of about 4×10^9 neutrinos cm^{-2} sec^{-1}, which can probably be detected using a 10 000 gal tank of CCl_4 in a mine (R. Davis, private communication). The modified proton-proton chain may produce the large lithium abundances in certain giant stars. Thanks are due W. A. Fowler for bringing the work of reference 1 to the writer's attention before publication.

[1] H. D. Holmgren and R. L. Johnston, Bull. Am. Phys. Soc. Ser. II, 3, 26 (1958), and private communication.
[2] R. L. Sears (private communication).

XA2. Reactions Involving Medium-Light Nuclei.* H. REEVES AND E. E. SALPETER, *Cornell University.*—Thermonuclear reactions in very hot stars, consisting mainly of C^{12}, O^{16}, and Ne^{20} are studied. One important reaction is the compound nucleus formation of Mg^{24} in the collision between two C^{12} nuclei, which will occur at temperatures of about 5 to 7×10^8°K. The calculated rates of such reactions depend very strongly on the assumed effective interaction radius for the process. This radius was estimated by extrapolation to low energies of an analysis of laboratory experiments on similar reactions. Calculations were also carried out for $C^{12}+O^{16}$, $O^{16}+O^{16}$, etc. Further experiments are suggested which would greatly improve the accuracy of the calculated rates. Other types of reaction chains, involving successive (α,γ) and (γ,α) reactions are also studied theoretically. Experimental information on the spin and parity of the 5.63-Mev level in Ne^{20} are urgently required for this purpose.

* Supported in part by a joint contract of the U. S. Atomic Energy Commission and the Office of Naval Research.

XA3. Proton Groups from the Reactions $Li^7(Li^7,p)B^{13}$ and $Be^9(Li^6,p)C^{14}$.* C. S. LITTLEJOHN AND G. C. MORRISON, *University of Chicago* (introduced by S. K. Allison).—The reactions $Li^7(Li^7,p)B^{13}$ and $Be^9(Li^6,p)C^{14}$ are exothermic, with Q values of 5.97 and 15.12-Mev, respectively. By searching for proton groups at 90° in the laboratory system arising from bombardment with 2-Mev Li^+ ions, energy levels in B^{13} and C^{14} may be detected. B^{13} may be explored up to 7.8 Mev of excitation, and C^{14} up to 16.3 Mev. The protons are detected in a scintillation counter gated by a proportional counter and the pulses are displayed on a pulse-height analyzer. Range difference determinations, using standard proton groups for calibration, are used for energy measurements. In the case of B^{13}, no proton groups in the kinetic energy range from 6.40 Mev (arising from the ground state of B^{13}) down to 3.5 Mev are observed, meaning no detectable levels in B^{13} below 2.9 Mev of excitation. Lower energy proton groups would be interfered with by deuterons and tritons from competing reactions and this region is under investigation. In the case of C^{14}, the ground-state group and groups corresponding to the known levels between 6.1 and 8.5 Mev of excitation have been seen. The work of McGruer, Warburton, and Bender on $C^{13}(d,p)C^{14}$ has shown that at their deuteron energy of 14.8 Mev the stripping mechanism predominates, whereas by the lithium beam method the reaction cannot proceed by a single nucleon transfer.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

XA4. Elastic Scattering of C^{12} from Gold.* H. L. REYNOLDS AND E. GOLDBERG, *University of California Radiation Laboratory, Livermore.*—The angular distribution of C^{12} ions elastically scattered by gold has been measured at the following laboratory energies: 118, 101, 79.4, and 73.6 Mev. The heavy ions from the Berkeley HILAC entered the scattering chamber through a collimator and were scattered by a gold foil 0.75 mg/cm² thick. Two Ilford El plates recorded scattered ions from 19° to 153°. In all cases the differential cross sections exhibit a Coulomb-like behavior at small angles, a rise above Coulomb of about twenty-five percent as the scattering angle increases, and then a rapid drop below Coulomb in much the same manner as alpha particles scattered from heavy elements in the 20–40 Mev range. Application of the Blair[1] "sharp cutoff" model gives an interaction radius of $11.8\pm0.2\times10^{-13}$ cm at all four energies.

* This work done under the auspices of the U. S. Atomic Energy Commission.
[1] J. S. Blair, Phys. Rev. 95, 1218 (1954).

XA5. Nuclear Reaction Cross Section from the Nitrogen Bombardment of Sulfur. DAVID E. FISHER,* *Oak Ridge National Laboratory*† (introduced by A. Zucker).—Thick targets of ZnS, containing natural sulfur, were bombarded with 28-Mev nitrogen ions in the ORNL 63-inch cyclotron. The compound nucleus resulting from bombardment of sulfur-32 with 28-Mev nitrogen ions is V^{46}, with an excitation energy of 33.3 Mev. Nickel foils of varying thickness were used to degrade the beam energy. Each target was chemically processed to separate the different radioactive reaction products, and the various fractions were beta counted. The following nuclear reactions were detected: (1) $S^{32}(N^{14},p)Ti^{45}$, (2) $S^{32}(N^{14},2p)Sc^{44}$, (3) $S^{32}(N^{14},2p\pi)Sc^{43}$, (4) $S^{32}(N^{14},2\alpha)K^{38}$, and (5) $S^{32}(N^{14},N^{13})S^{33}$. The yields as a function of incident energy for these reactions were differentiated to obtain excitation functions. Reaction (5) is identified as a transfer reaction. Its cross sections agree well with the systematics of previously studied nitrogen-induced reactions of this type. The cross sections for reactions (1), (2), (3), and (4) are compared with calculations based on the statistical theory of compound nucleus decay.

* ORINS fellow from The University of Florida.
† Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

XA6. Variation of the Ternary U^{235} Fission Cross Section with Neutron Energy.* E. J. SEPPI, *Hanford Laboratories.*—Large differences exist in the results of various experimenters[1] for the value of the ratio fo the neutron induced ternary to binary fission cross section of uranium-235. It has been

suggested that these differences are the result of a variation of this ratio with neutron energy combined with differences in the neutron spectrums used for the measurements. A variation in this ratio with energy has theoretical interest because of the possibility that it is a sensitive indicator of the collective mode of vibration passed during fission. Using a multipe plate fission detector and monoenergetic neutrons from a crystal spectrometer, we have measured the ratio of the ternary to binary fission cross sections. We find the ratio constant to a precision of about 1% in the energy region 0.04 to 0.40 ev and 3 to 6% in the energy region 0.04 to 8.7 ev. Since interference effects are not seen, we conclude that in this energy region the compound uranium-236 nucleus passes the same mode (or average modes) of collective vibration for either ternary or binary fission.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. B. Fulmer and B. L. Cohen, Phys. Rev. **108**, 370 (1951).

XA7. X-Ray Emission from Fission in the Region from 1.5 kev to 40 kev. R. E. CARTER, J. J. WAGNER, AND M. E. WYMAN, *Los Alamos Scientific Laboratory.**—The low-energy photons emitted during thermal neutron fission of U^{235} have been examined. Using proportional counters and small scintillators, structure in the pulse-height distribution has been observed throughout this region of energies. Only photons of about 30 kev have been reported.[1,2]

* This work was done under auspices of the U. S. Atomic Energy Commission.
[1] Voitovetskii, Levin, and Marchenko, Soviet Phys. JETP **5**, 184 (1957).
[2] Skliarevskii, Fomenko, and Stepanov, Soviet Phys. JETP **5**, 220 (1957).

XA8. The Electron Spectrum from U^{235} Fission Fragments from 1 to 8 Mev. J. J. WAGNER, R. E. CARTER, F. REINES, AND M. E. WYMAN, *Los Alamos Scientific Laboratory.**—The present experiment is designed to measure this spectrum accurately enough so that the derived antineutrino spectrum can be used in the interpretation of free neutrino experiments.[1] The first measurements, by Muehlhause and Oleksa,[2] were performed in 1955 before some of the requirements became apparent. In the present experimental arrangement, the total background, including fission gammas, is reduced to 5%. In the course of the experiment, the variation of the electron spectrum with time following the onset of neutron irradiation is observed.

* This work was done under auspices of the U. S. Atomic Energy Commission.
[1] Discussed in an article by F. Reines and C. L. Cowan, Phys. Today **10**, 12 (August, 1957).
[2] C. O. Muehlhause and S. Oleksa, Phys. Rev. **105**, 1332 (1957).

XA9. Abstract withdrawn.

XA10. Coulomb Excitation of the Second 2^+ State in Isotopes of W, Os, and Pt. F. K. MCGOWAN AND P. H. STEELSON, *Oak Ridge National Laboratory.*—The location of the second 2^+ state has been established for five even-even nuclei by means of Coulomb excitation produced by 4- to 5-Mev protons. The relatively weak excitation of these states is detected by a measurement of the gamma-ray yields and by a coincidence measurement of the cascade gamma rays. The location of the second 2^+ state in kev and the $B(E2)$ for excitation in units of the Weisskopf independent-particle estimate are: W^{184}, 891 ± 9, 5.5 ± 1.6; W^{186}, 730 ± 7, 5.5 ± 1.0; Os^{188}, 633 ± 6, 6.3 ± 1.9; Os^{190}, 557 ± 6, 4.3 ± 1.0; and Os^{192}, 489 ± 5, 4.6 ± 1.0. Using the observed branching ratio of cascade to crossover, the $B(E2)$ for decay of the cascade transition from these states has been determined on the assumption that the transition is predominantly $E2$. The location of the second 2^+ state in Os^{190} and Os^{192} is in fair agreement with the Coulomb excitation measurements of Barloutand *et al.*[1] From bombardment of a target of platinum containing 66% Pt^{196}, we find that the $B(E2)$ for excitation of the well-known 2^+ state at 688 kev is less than 1/25 of the independent-particle estimate.

[1] Barloutand, Lehmann, and Leveque, Compt. rend. **245**, 523 (1957).

SATURDAY AFTERNOON AT 2:00

Sheraton-Park, Continental Room

(R. E. BELL presiding)

Positronium; Muonium; Various Nuclear Topics

Y1. Positron Lifetime in Metals.* M. A. B. BÉG AND P. STEHLE, *University of Pittsburgh.*—The model for positron annihilation of the preceding paper, assuming rapid exchange of the bound electron with conduction electrons, gives a mean lifetime of 5×10^{-10} sec.[1] An attenpt has been made to reduce this discrepancy by taking account of the annihilation with unbound electrons, treating screened Coulomb interactions with perturbation theory. It is found that the exclusion principle severely limits this process in such a way, however, that the uniformity of lifetimes from metal to metal is preserved. Quantitative agreement is still not good, the mean lifetime obtained being 4.2×10^{-10} sec. Possible refinements of the model and problems of angular correlation[2] will be discussed.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.
[1] T. R. Gerholm, Arkiv, Fysik **10**, No. 38 (1956).
[2] G. S. Lang and S. de Benedetti, Phys. Rev. **108**, 914 (1957).

Y2. A Measurement of the Effect of Static Electric Field on the Formation of Positronium in Gases.* FELIX E. OBENSHAIN AND LORNE A. PAGE, *University of Pittsburgh.*—It is well

known that the application of a static electric field enhances the formation of positronium in a gas. The increase in formation is due to the acceleration of low-energy positrons back into the energy region of the Ore gap. On the basis of present knowledge, one would not expect the annihilation rate to depend on the sign of the electric field. The results of this experiment show that the two-quanta annihilation rate is dependent on the sign of the applied electric field with respect to the initial momentum direction of the positron. The Na^{22} source may be oriented so that the initial momentum of the positron is either in the positive or negative z direction. The experimental set up is the same as that used to measure the polarization of Na^{22} positrons reported by Page and Heinberg. In this experiment we measure the two-quanta yield of positronium in argon by strict 180° angular correlation. No known systematic errors are sufficient to account for the observed effect. It does not seem possible to explain the observations on the basis of an $(\mathbf{E}\cdot\mathbf{p})$ term due to the short mean free path of the positron.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and supported by the Office of Ordnance Research, U. S. Army.

Y3. Experimental Evidence for Electron Exchange Conversion of ^3S Positronium and for the Chemical Binding of Positrons to Negative Ions.* ROBERT DE ZAFRA, *University of Maryland.*—Measurements have been made on the effect of certain ions on positronium annihilations in aqueous solutions by studying the changes induced in the angular correlation of the annihilation radiation. The paramagnetic ions Mn^{++} and Co^{++} and the molecular ions NO_2^- and NO_3^- (dissolved from their chloride and sodium salts, respectively) have been used. A control solution of NaCl is found to produce no appreciable effects. The paramagnetic ions produce considerable narrowing of the angular distribution compared to that for pure water, while the NO_2^- and NO_3^- ions produce a strong broadening. The first of these effects is interpreted in term of triplet-to-singlet conversion of positronium by electron exchange. The second effect can be explained by chemical binding of positrons to the ions. This bears out the recent suggestion by Green and Bell, who find that NO_2^- and NO_3^- produce a strong reduction in the intensity of the τ_2 lifetime component but not of the lifetime itself. Evidence will also be given which shows that the quenching of the τ_2 lifetime in benzene produced by the free radical diphenyl picryl hydrazyl is *not* caused by any type of electron exchange as has been supposed, but must also be attributed to chemical binding, this time probably involving capture of *positronium* by the free radical.

* Research supported by the Department of Defense.

Y4. Formation of Positronium in Metals.* P. STEHLE AND M. A. B. BÉG, *University of Pittsburgh.*—The constancy of the lifetime of positrons in metals from metal to metal[1] suggests that positronium forms an intermediate stage in the annihilation process,[2] even though the resulting lifetime does not agree quantitatively with that observed. We have made an estimate of the rate of formation of positronium by radiationless capture of a conduction electron by a positron. For metals with not too high an electron density (Fermi energy not greater than 5 ev) the rate of formation is several orders of magnitude greater than the annihilation rate, lending credence to this model. In the following paper[3] an attempt is made to make the model give more quantitative results, for the annihilation rate.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.
[1] R. E. Bell and R. L. Graham, Phys. Rev. 90, 644 (1953).
[2] R. L. Garwin, Phys. Rev. 91, 1571 (1953).
[3] McColm, Hughes, Malone, Lederman, and Lurio, Bull. Am. Phys. Soc. Ser. II, 3, 229 (1958).

Y5. Further Evidence for Muonium Formation in N_2O.* D. MCCOLM, V. W. HUGHES, AND D. MALONE, *Yale University,* AND L. LEDERMAN, *Columbia University,* AND A. LURIO, *IBM Watson Laboratories.*—In a previous abstract the particularly large depolarization of positive muons stopped in N_2O gas was reported for an experiment similar to that of Garwin, Lederman, and Weinrich. One explanation for the low observed value of (peak counts)/(valley counts) is the abundant formation of muonium. To test this possibility further the effect of a small magnetic field H_z along the direction of the incoming muon beam on the positron counting rate parallel to this direction has been measured. The positron counting rate arising from μ-meson decays is observed under two field conditions: (i) $H_z=0$ and a vertical field $Hy=2$ gauss, (ii) $H_z=15$ gauss; $Hy=2$ gauss. A change in counting rate by a factor 1.09 ± 0.02 is found without correction for background. If π mesons are stopped in the gas, the corresponding measurement gives 1.01 ± 0.01. With the assumptions that all muons form muonium in its ground state and that the magnetic substates are unequally populated as expected for initially polarized muons, a ratio of counting rates equal to about 1.16 is expected due to the retention of the polarization of the $m=-1$ magnetic substate in the H_z field. It is felt that the result of this experiment adds considerable support to the view that muonium formation occurs for muons stopped in N_2O.

* This research has been supported in part by the Office of Naval Research, U. S. Atomic Energy Commission, and Air Force Office of Scientific Research.

Y6. Magnetic Moment of Mu-Mesonic Atoms.* V. W. HUGHES, *Yale University,* AND V. L. TELEGDI, *University of Chicago.*—Nonconservation of parity in the decay of π and μ mesons may make possible precise measurements of the magnetic moment of mu-mesonic atoms in their ground[2] $S_{\frac{1}{2}}$ state by the observation of Zeeman transitions. The magnetic moment, m, of the μ meson attached to a nucleus of charge $+Ze$ and spin $I=0$ differs from the magnetic moment, m_f, of the free μ meson by a relativistic binding factor which can be calculated form the Dirac equation for the mu-meson atom. For a point charge model of the nucleus $m=m_f[1-\alpha^2Z^2/3]$, in which α is the fine structure constant.[1] For an extended spherically symmetric nucleus, $m=m_f[1-2\langle T\rangle/(3m_\mu c^2)]$, in which m_μ=mass of mu meson and $\langle T\rangle$ is the expectation value of the kinetic energy of the mu meson in the mesonic atom. For lead, $\alpha^2Z^2/3=0.12$. Since the radius of a mu-mesonic atom with large Z is of the order of the nuclear radius,[2] the two expressions for the correction to the magnetic moment give values which differ by a substantial fraction of the correction itself ($\sim\frac{1}{3}$ for Pb). Hence, the precise measurement of these magnetic moments may offer a useful tool for the study of nuclear structure.

* This work partially supported by the Air Force Office of Scientific Research, U. S. Atomic Energy Commission, and Office of Naval Research.
[1] G. Breit, Nature 122, 649 (1928); H. Margenau, Phys. Rev. 57, 383 (1940). An intuitive interpretation of this correction is that part of the moment arises from the small component ($P_{\frac{1}{2}}$) which has a different Landé g factor.
[2] V. L. Fitch and J. Rainwater, Phys. Rev. 92, 789 (1953).

Y7. Electron Pair Production in Hydrogen by the Photon Beam of the Cornell Synchrotron.* E. L. HART, G. COCCONI, V. T. COCCONI, AND J. M. SELLEN, *Cornell University.*—Electron pair production in the field of the proton (pairs) and in the field of the electron (triplets) has been studied by passing a 1-Bev bremsstrahlung beam, hardened by 2.75 radiation lengths of lithium hydride, through a hydrogen filled diffusion cloud chamber operating in a magnetic field. Twenty-six hundred events including one thousand triplets with recoil electron momentum greater than 0.15 Mev/c are being analyzed for total energy, energy distribution between numbers, opening angle of the pair momentum, and angle

distribution of the triplet recoil electron, and ratio of pairs to triplets. Preliminary results, based on one-thousand events, indicate that the pair opening angle distribution follows Borsellino's[1] calculation closely. The momentum distribution of the triplet recoil electrons is in fair agreement with an evaluation by Rohrlich[2] and the ratio of pairs to triplets over a wide range of energies above 100 Mev is roughly unity.

* Supported in part by the joint program of the Office of Naval Research the U. S. Atomic Energy Commission.
[1] A. Borsellino, Phys. Rev. **89**, 1023 (1953).
[2] J. Joseph and F. Rohrlich, Revs. Modern Phys. (to be published).

Y8. Negative Helium Ion Fraction in an Equilibrium Beam in Hydrogen Gas.* THEODORE JORGENSEN, JR., CHRIS KUYATT, AND C. A. SAUTTER, *University of Nebraska*.—A beam of helium ions is sent through a region containing hydrogen gas at about 30 μ pressure. The emerging equilibrium beam is analyzed in a magnetic field in a vacuum. The ratio of the He^- ions[1-3] to the He^+ ions will be shown for energies from 40 to 200 kev. The broad maximum in the He^-/He^+ ratio is 6.5×10^{-4} and occurs at 100 kev. Using other data[4] the ratio of He^- to the total beam is shown to have the maximum of 2.1×10^{-4} at 130 kev.

* Work supported by the U. S. Atomic Energy Commission.
[1] E. Holøien and J. Midtdal, Proc. Phys. Soc. (London) **A68**, 815 (1955).
[2] P. M. Windham *et al.*, Bull. Am. Phys. Soc. Ser. II, **2**, 11 (1957).
[3] V. M. Dukelskii *et al.*, J. Exptl. Theoret. Phys. (U.S.S.R.) **3**, 764 (1956).
[4] Stein, Barnett, and Evans, Phys. Rev. **96**, 96, 973 (1954).

Y9. Collection of Ions Produced by Alpha Particles in Air. Z. BAY AND H. H. SELIGER, *National Bureau of Standards*.—One of the important assumptions in the measurement of the average energy expended in producing an ion pair in air (W_{air}) by alpha particles is that recombination effects can be accounted for by extrapolation to infinite field strength on the basis of the Jaffé theory. This extrapolation method was recently challenged by Wingate, Gross, and Failla[1] who concluded, from an observed pressure-dependence for saturation ionization currents, that values of W_{air} for alpha particles obtained at atmospheric pressure are in serious doubt. As a part of our program to determine W_{air} for alpha particles, we have therefore investigated the range of validity of the extrapolation methods under usual conditions of measurements. Our measurements in air with Po^{210}-alpha particles over a pressure range from 0.25 to 2.5 atmos gave extrapolated saturation currents independent of pressure within $\pm0.3\%$, the experimental uncertainty of our data. We therefore conclude that the usual extrapolation methods can be applied with confidence in absolute W measurements. The experimental techniques used and the differences between our results and the conclusions of Wingate, Gross, and Failla[1] will be discussed.

[1] Wingate, Gross, and Failla, Phys. Rev. 105, 929 (1957).

Y10. Charge Transfer Cross Sections for Protons in H_2.* T. M. DONAHUE, W. H. KASNER,† AND J. NOLAN, *University of Pittsburgh*.—Measurements of the cross sections for electron capture and loss by protons and hydrogen atoms in H_2 in the energy range from 2.4 to 70 kev have been made by a combination of new methods. These involve the employment of a sequence of nine identical condensers to collect slow ions in the measurement of σ_{10} or to remove charged particles in the measurement of σ_{01} and $(\sigma_{10}+\sigma_{01})$. The method eliminates uncertainty concerning end corrections and secondary emission. The results for σ_{10} lie considerably below those previously reported, the maximum of 3.6×10^{-16} cm^2 occurring at 0.49 kev. Below this peak σ_{10} is accurately proportional to the one-third power of the energy.

* Supported by the Office of Naval Research.
† Present address: The University of Maryland.

Y11. Investigation of the Energy Loss per Ion Pair for Protons in Various Gases.* H. V. LARSON, *General Electric Company*.—Values of w for protons in A, N_2, CO_2, air, and tissue equivalent gas were determined. A 2-Mev positive ion accelerator was used as the source of protons. The energy of the protons was determined by a precision gaussmeter that was calibrated by the $Li(p,n)$ and $T(p,n)$ reactions. These protons were scattered from a gold foil into a parallel plate ionization chamber. The fast electron pulses were collected on one electrode, amplified, and counted. The positive ion charge was collected on the other electrode and measured by means of a standard capacitor that was connected between the input and feedback terminals of a vibrating-reed electrometer. The value of w for 2-Mev protons in argon gas is 26.53 $\pm$0.24 ev/ip; the other w values will be reported at the meeting.

* This paper describes in part, work done under contract between the General Electric Company and the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

NBS, East Building

(E. BURSTEIN presiding)

Solid-State Physics, Mostly Nonmetals

Z1. Shock-Induced Phase Transitions in Nonmetallic Elements. R. GROVER, R. H. CHRISTIAN,* AND B. J. ALDER, *University of California, Livermore*.—The amazing rapidity with which phase transitions can be induced by shocks has been confirmed by further experiments[1] on phosphorus and carbon. In addition the phosphorus data show that the transition pressures differ significantiy from static compression data. The amorphous phases of carbon and phosphorus (red) irreversibly transform to the crystalline phase as confirmed by conductivity, recovery, and equation-of-state experiments. Both of these transformations are of a similar crystalline nature and require the establishment of long-range order. The one for phosphorus occurs at about 25 000 atmospheres and 200°C while in static experiments at 20°C, at least 45 000 atmospheres is required. The transition from yellow phosphorus to black, on the other hand, which involves the breaking of bonds, occurs dynamically at about 80 000 atmospheres and a somewhat higher temperature, as opposed to 12 000 atmospheres and 200°C statically.

* Now at General Electric Co., Philadelphia.
[1] R. H. Christian and B. J. Alder, Tenth Anniversary Meeting of the Division of Fluid Dynamics.

Z2. Electrical Conduction in Type *A* Zeolite. W. PERIA, *Honeywell Research Center* (introduced by O. S. Lutes).—Zeolites are a class of aluminosilicates having a three-dimensional framework structure, featuring the occurrence of large cavities in the crystallographic unit cell. A structure

containing such a periodic array of *vacancies*, whose density is independent of temperature, is interesting from the point of view of solid-state physics. The electrical conductivity of two forms of *Type A* zeolite,[1] a synthetic material obtained from the Linde Company, have been measured. Both of these forms have the same framework structure, one is a sodium aluminosilicate while the other is the calcium substituted form of the same material. The results of the conductivity vs temperature measurements are consistent with simple ionic conductivity theory and give activation energies of 0.58 and 1.19 ev for the sodium and calcium forms, respectively. This strongly suggests that the conduction is by cations, that the activation energy is proportional to the cationic charge and therefore that the electrostatic potential barrier is independent of the cation.

[1] T. B. Reed and D. W. Breck, J. Am. Chem. Soc. **78**, 5972 (1956).

Z3. Anomalous Dispersion of X-Rays in ZnO.* J. R. Townsend, G. A. Jeffrey, and P. Harrison, *University of Pittsburgh*.—An experimental study of deviations from Friedel's law has been made with Mo and CuK_α radiation using single crystals of ZnO. The measurements give values of the out-of-phase atomic scattering factor for zinc, $\Delta f_{Zn}''$, as a function of the scattering angle, 2θ, for MoK_α radiation. Comparison with the theoretical value of Hönl[1] and of Parratt and Hempstead[2] give very poor agreement for $(\sin\theta/\lambda)>0.6$. The large variation of $\Delta f_{Zn}''$ with 2θ which was found suggests that the usual calculation of the crystal structure factor, F, from the anomalous atomic scattering factor is invalid for ZnO. A re-evaluation of the theory of anomalous scattering showed two apparent deficiencies: (a) Hönl's theory is intended only for the scattering of an isolated atom, no effects arising from the crystal lattice were considered by him. This effect is large if the important excited states have a low positive energy, so in itself it should not produce the observed ZnO results. (b) If two or more anomalously scattering atoms are present in each primitive unit cell, complications in the theory arise which render invalid the use of anomalous atomic scattering factors.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] See R. W. James, *The Optical Principles of the Diffraction of X-Rays* (G. Bell and Sons, London, 1954), Chapt. IV.
[2] L. G. Parratt and C. F. Hempstead, Phys. Rev. **94**, 1593 (1954).

Z4. Neutron Diffraction Study of $NiFeCrO_4$ and $NiFe_{0.5}Cr_{1.5}O_4$.* S. J. Pickart, *U. S. Naval Ordnance Laboratory and University of Maryland*, and R. Nathans, *Pennsylvania State University and Brookhaven National Laboratory*.—Interesting magnetic and crystallographic behavior has been reported for the mixed spinel series $NiFe_{2-t}Cr_tO_4 (0\leq t\leq 2)$ by McGuire and Greenwald.[1] The structure of two of these compounds, with $t=1.0$ and 1.5, has been investigated by neutron diffraction. The data in this case are not sensitive to the distribution of nickel and iron between the lattice sites, but the chromium can definitely be assigned to the octahedral position. There is no evidence in the low-temperature patterns for ordered triangular spin configurations of the kind proposed by Yafet and Kittel.[2] The magnetic scattering can be accounted for on the Néel scheme, except that for $t=1.5$ the moment of the octahedral sublattice is lower than would result for parallel alignment of spins. Diffraction studies were also performed with an external magnetic field to check for the anomalous behavior previously observed[3] in the chromium-substituted manganese ferrite.

* This work was carried out at Brookhaven National Laboratory under the auspices of U. S. Atomic Energy Commission and National Security Agency.
[1] T. R. McGuire and S. W. Greenwald, Bull. Am. Phys. Soc. Ser. II, **3**, 43 (1958).
[2] V. Yafet and C. Kittel, Phys. Rev. **87**, 290 (1952).
[3] S. J. Pickart, Bull. Am. Phys. Soc. Ser. II, **3**, 42 (1958).

Z5. Structure of Al_2CO; a Light Element Member of a III/½(IV+VI) Class of Compounds.* G. A. Jeffrey and H. Lynton, *University of Pittsburgh* (introduced by J. Townsend).—Al_2CO is isomorphous with AlN; it has the hexagonal wurtzite-type lattice, $B.4$, with $c=5.06$, $a=3.17$ A. In addition to the sharp x-ray reflexions which define this lattice, single crystal photographs also show strong diffuse reflexions which can be interpreted on the basis of the same lattice with a short range periodicity of $2c$ and $\sqrt{3}a$. The diffuse pattern remains unchanged over temperature range −70° to 850°C. This compound can be regarded as a member of a variation of the well-known III/V type in which the group V elements are replaced half by group IV and half by group VI elements, (e.g., hypothetical, B_2CO, Al_2GeSe, In_2GeSe). As is the normal III/V compounds, the structure type should change from hexagonal $B.4$ to cubic $B.3$ with the combinations of atoms with smaller electronegativity differences.[1,2] It is believed that the long range disorder in the arrangement of the atoms on the lattice is an important contributing factor to the stability. Although no other compounds of this subtype have yet been reported, it is likely that they could exist since some analogous ½(II+IV)/V compounds have recently been described.[3]

* Supported by the Office of Ordnance Research, U. S. Army.
[1] Jeffrey, Parry, and Mozzi, J. Chem. Phys. **25**, 1024 (1956).
[2] Keffer and Portis, J. Chem. Phys. **27**, 675 (1957).
[3] Goodman, Nature, **828** (1957).

Z6. Calculation of the Valence Band Structure in BeO.* W. O'Sullivan, *University of Pittsburgh*.—The LCAO approximation is applied toward a description of the valence band in BeO, in which only the closed shell $Be(1s)^2O(2p)^8$ configuration is considered. The treatment of closed shell systems, used by Löwdin[1] in determining the cohesive energy in alkali halide crystals, is adopted for this calculation. Thus, no account is taken of the deformation of the oxygen valence electron distribution by the polarization field along the c axis of the wurtzite-type crystal. We use the $O^{--}(2p)$ radial function calculated by Yamashita and Kojima[2] for MgO, and include the correction for nonorthogonality of atomic orbitals centered on different lattice sites. The valence band width is found to be 18 ev and the maxima lie in the (k_x,k_y) plane rather than along the k_z axis. We expect the 18 ev width represents an overestimate, a result that follows reasonably from the use of the $MgO,O^{--}(2p)$ function.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] P. O. Löwdin, Thesis, Uppsala, 1948.
[2] J. Yamashita and Kojima, J. Phys. Soc. (Japan) **7**, 261 (1952).

Z7. Photoproduction of *F* Centers in KI Crystals. James H. Parker, Jr., *Westinghouse Research Laboratory*.—The quantum efficiency has been measured for F centers produced by uv photons in KI crystals at room temperature. The efficiency was obtained by irradiating the crystal with a known number of uv photons and then measuring the change in absorption at the maximum of the F band. The change in absorption along with the absorption cross section at the maximum of the F band gives directly the number of centers formed. This cross section was determined for KI by a chemical method and a value of $1.7(\pm 0.02)\times 10^{-16}$ cm² obtained. For determining the change in F band absorption an ac difference method was used, with which the minimum detectable change in F center concentration was about 1×10^{11}/cm³. For both Harshaw and "home grown" crystals the quantum efficiency at the start of coloring was found to be approximately independent of uv wavelength from 2100 A to 2300 A and to have the value of 0.1. This value is a factor of ten smaller than that reported by Smakula.[1] For increasing numbers of absorbed uv photons the efficiency was found to continuously decrease

from its initial value, the rate of decrease being strongly dependent upon the uv wavelength.

[1] Alexander Smakula, Z. Physik 63, 762 (1930).

Z8. Evaluation of Electric Field Action on Photoconductive Response. A. BRAMLEY, *Du Mont Laboratories.*—Evaluation of experimental results[1] on slurry type photoconductors reveals that at least two different processes have direct bearing on photoconductive response characteristics. These experiments were either on rapid quenching with high intensity short (~10 μsec) light pulses or no slow quenching with strong electric fields applied perpendicular to photoconductor surface. The following two mechanisms are among those contributing to nonlinearity of slurry-type photoconductive response: (1) The change in capacity with light level may amount to a factor between 2 and 10. Current pulses are also obtained with capacity (~1000 μμf) in parallel with load resistor (~1 meg) in series with photoconductor but their time constant is longer. (2) The surface states may play a significant role through the variation in rate of recombination with electric intensity perpendicular to over-all direction of photocurrent or through the space charge limitations in the surface states at high potential differences (just below breakdown) in direction of photocurrent.

[1] A. Bramley, Bull. Am. Phys. Soc. Ser. II, 3, (1958).

Z9. Primary Pyroelectricity in Barium Titanate Ceramics. W. I. DOBROV, T. J. DIESEL, AND T. A. PERLS, *Lockheed Missle Systems Division.*—The total pyroelectric effect observed in polycrystalline barium titanate ceramics has been investigated to determine the possible existence of a primary pyroelectric effect. Measurements were made from −80°C to +130°C of the hydrostatic piezoelectric coefficient by a pressure-pulse method; of Young's modulus by determining resonance frequency; of the total pyroelectric coefficient by means of chopped heat pulses; and of the thermal coefficient of expansion. These data, together with published values of Poisson's ratio, and of the specific heat, were sufficient to determine the piezoelectric and primary pyroelectric contributions to the total observed effect. The data show that the total pyroelectric effect observed is opposite in direction to the piezoelectric contribution resulting from volumetric changes. It is therefore established that there exists a primary pyroelectric effect in polycrystalline barium titanate. Its contribution is approximately twice the piezoelectric contribution near room temperature (secondary pyroelectricity). The inherent time constant for generation of electrical signals from heat pulses was found to be less than 12 μsec, a limit imposed by the experimental techniques used. Practically, sensitivities to heat radiation for barium titanate ceramics are not competitive with good bolometers. However, barium titanate sensors are simple to build and may be useful in measuring beams of large cross section.

Z10. Vitreous and Crystalline Semiconducting Films of Sb_2Se_3.* T. E. JOHNSON AND LEE GILDART, *University of Kentucky.*—Vitreous films of antimony triselenide, ordinarily a crystalline semiconductor in the bulk, have been prepared by vacuum evaporation on Pyrex. When heated from room temperature to about 250°C they show an initial (irreversible) activation energy of 1.8 ev, but after a short while the films devitrify to a polycrystalline form with an activation energy of 1.1 ev (reversible). The large resistivity discontinuity produced in bulk Sb_2Se_3 by addition of 0.1% excess selenium[1,2] was not found in the films, either in the vitreous or the crystalline form. The vitreous films had resistivities of the order of 10^7 ohm-cm at room temperature, and the devitrified films of the order of 10^4 ohm-cm, and neither showed any appreciable variation of resistivity *vs* composition. Both forms showed moderate photoresponse in the visible, surprisingly flat from about 5000 A to beyond 7500 A. All films were of the order of 200 μg/cm² in thickness; upon devitrification there was an apparent shrinkage revealed by fissuring in some case, indicating a density increase of about 5%.

* This research supported by the Air Force Office of Scientific Research.
[1] Cullity, Telkes, and Norton, J. Metals 2, 47 (1950).
[2] D. F. Clifton and L. Gildart, Bull. Am. Phys. Soc. Ser. II, 1, 226 (1956).

Z11. Effects of Evaporation Conditions on Humidity Sensitivity and Response of Evaporated KPO_3 Films.* F. E. JONES, A. WEXLER, S. B. GARFINKEL, AND R. A. MACQUARRIE, *National Bureau of Standards.*—The effects of vacuum evaporation conditions on the properties of evaporated films of potassium metaphosphate, particularly the effects on the electrical resistivity and response to changing humidity have been studied. The production of films reproducibly and with some predetermination of structure and properties can be accomplished by controlling conditions before, during, and after the evaporation and making measurements of the various parameters. Many of the factors which influence the growth and structure of evaporated films in general have been determined through the efforts of many workers in several fields. In this work a list of many of the influencing conditions and parameters which can be controlled or at least measured throughout the film production process and subsequent treatment was made and served as a basis for a program of controlled evaporations of KPO_3 onto glass substrates. Through the variation of these conditions and parameters the electrical resistivities and response times of the films were varied over several orders of magnitude.

* This work is part of a program in aerological instrumentation sponsored by the Aerology Division of the Bureau of Aeronautics, Department of the Navy.

Z12. Fragmentation of n-C_3H_7T and s-C_3H_7T by Beta Decay.* S. WEXLER AND D. C. HESS, *Argonne National Laboratory.*—The patterns of positively charged fragments resulting from beta decay of tritium in isolated molecules of the isomeric pair, n-C_3H_7T and s-C_3H_7T, have been determined by mass spectrometric techniques. More than 23 decomposition products are observed from each monotritiated propane. The masses, but not the abundances, of the ions are the same as those found in electron impact studies. With few exceptions the fragmentation spectra of the two propanes are markedly similar. The allyl ion $C_3H_5^+$ is considerably more pronounced in the mass spectra from $CH_3CH_2CH_2T$ than from CH_3CHTCH_3, while the reverse is true for the ions $C_3H_7^+$, $C_3H_5T^+$ and H^+. The initial product $(C_3H_7He^3)^+$ of the nuclear transition is found only in trace amounts and charged He^3 is absent. The disruption processes induced by β^- emission in the two propanes are thus similar to those observed[1] in CH_3T and C_2H_5T.[2] Evidence is found for hydrogen atom rearrangement in the excited propyl ions. The data cast some doubt on the existence of the protonated ring structure[3] for the normal propyl ion formed in these experiments.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Frances Pleasonton and A. H. Snell, Bull. Am. Phys. Soc. Ser. II, 3, 39 (1958).
[2] D. C. Hess and S. Wexler, Bull. Am. Phys. Soc. Ser. II, 2, 304 (1957).
[3] M. B. Wallenstein, *The Ionization and Dissociation of Molecules by Electron Impact*, thesis (University of Utah, 1951).

Z13. Analysis of the PVT Data for Several High Molecular Weight Hydrocarbons. W. G. CUTLER, W. WEBB, AND R. W. SCHIESSLER, *The Pennsylvania State University.*—Volume-pressure data to 10 kilobars for a series of structurally related, high molecular weight hydrocarbons have been determined by the High Pressure Laboratory[1] of The Pennsylvania State University. These high purity hydrocarbons are synthetically produced by the Hydrocarbon Laboratory[1] of The Pennsylvania State University. The experimental data have been smoothed graphically and both the Tait equation and the Hudleston equation have been fitted to the resulting isotherms. Compressibility decreases, for a given compound and temperature, with increasing pressure, the rate of decrease becoming smaller at higher pressures. Pronounced structural

dependence is apparent in the values of the compressibility but this effect lessens as the pressure increases. Isobars for each of the compounds studied have the same general form and are almost linear. The slopes of the isobars reveal a change in sign of $(\partial^2 v/\partial T^2)_P$ at elevated pressures. Isochores, drawn from the smooth curve volume-pressure data, are not straight lines. The slope of a given isochore, $(\partial P/\partial T)_v$, decreases with increasing pressure and temperature. Experimental values of the pressure for which $(\partial E/\partial P)_T=0$ (E is the internal energy of the liquid) have been found for some of the compounds studied. The volume here approximates the volume at atmospheric pressure and 0°K.

[1] This project known as American Petroleum Institute Research Project 42 is jointly supported by the American Petroleum Institute and The Pennsylvania State University.

Z14. Thermodynamic Properties of Disordered Lattices.* GEORGE WEISS AND ALEXEI MARADUDIN, *Institute for Fluid Dynamics and Applied Mathematics* (introduced by R. D. Myers).—A method is presented for evaluating various additive functions of the normal mode frequencies for a lattice made up of different kinds of atoms which are randomly distributed over the lattice sites. This method, which is based on an expansion of the additive function expressed as a contour integral, is applied to the case where the lattice is made up of atoms with two different masses M_1 and M_2 which occupy a given lattice site with probability p and $(1-p)$, respectively. Conditions under which the expansion converges are given for this case. The method is illustrated by some simple examples, and its generalization to more general disordered lattices is discussed.

* Supported by the Air Force Office of Scientific Research.

Z15. The Screw Dislocation in a Hookean Lattice.* ALEXEI A. MARADUDIN,† *University of Bristol* (introduced by R. D. Myers).—A simple model of a screw dislocation in a crystal lattice in which each atom interacts with its neighbors through Hooke's law forces is presented, and expressions for the displacement component and strain energy are obtained. Applications of the model to screw dislocations in alkali-halide crystals are discussed.

* Research supported in part by the Air Force Office of Scientific Research.
† Now at the University of Maryland.

SUPPLEMENTARY PROGRAMME

SP1. Magnet Design System for Azimuthally Varying Field (AVF) Cyclotron. H. G. BLOSSER, E. D. HUDSON, R. S. LORD, AND B. D. WILLIAMS, *Oak Ridge National Laboratory.**—The system described by Blosser *et al.*,[1] for designing an air cored AVF cyclotron magnet has been extended to ferromagnetic systems. Fields of a given magnet structure are determined by means of a high precision model magnet set up; these fields are processed in a digital computor as described in (1) so as to determine orbit properties and gauge corrections to the magnet structure. The cycle is iterated until magnet precision requirements, set by the number of ion revolutions, are satisfied. The system is rapid and precise, thereby allowing convenient design of a variable field AVF magnet for particle energies corresponding to a considerable number of ion revolutions. Application of this system to the design of a new variable energy, variable particle cyclotron will be described. In this device, the required variability in field shape is obtained by using pole face windings as shim elements. The iron and main coil structures are optimized for an average particle, and current settings in the trimming coils are then determined to provide the proper field for other particles.

* To be given at the end of Session C if the Chairman rules that time permits.
[1] Blosser, Trammel, and Moseley, Bull. Am. Phys. Soc. Ser. II, **2**, 10 (1957).

SP2. Rotating Crystal, Time-of-Flight Neutron Spectrometer, B. N. BROCKHOUSE, *Chalk River Laboratories.**—In studies of solid and liquid dynamics by neutron spectrometry three types of instruments have been used to date; crystal spectrometers (Chalk River), filter time-of-flight apparatus [Brookhaven and Chalk River (differential filter)], and mechanical monochromator time-of-flight apparatus (Saclay). A new instrument in use at the NRX reactor combines advantages of each type with unique features of its own. A single crystal, rotating at high speed in a collimated neutron beam, reflects bursts of neutrons of energy determined by the Bragg law through a collimator set at an angle to the incoming beam. The bursts of monoenergetic neutrons impinge on the specimen and their energy after scattering is determined by time-of-flight. Useful "burst-focusing" properties exist. For $\lambda>4A$ higher orders and fast neutrons are eliminated by a cooled beryllium filter. At shorter wavelengths a new type of filter, consisting of large quartz crystals cooled to liquid nitrogen temperature, reduces fast neutrons and order contamination by virtue of the energy dependence of thermal inelastic scattering. The current version employs two 111 reflecting planes of an aluminum crystal rotating at 8200 rpm, and has a resolution at 4 A of about 1.5% in wavelength or 1.5×10^{-4} ev in energy.

* To be given at the end of Session L if the Chairman rules that time permits.

SP3. Screw Dislocation Core Structures in Sodium Chloride. I.*† ALEXEI A. MARADUDIN,‡ *University of Bristol* (introduced by R. D. Myers).—The positions of the ion rows at the core of a screw dislocation in sodium chloride have been calculacted by minimizing semi-analytically the energy of interaction of these rows with themselves and the rest of the lattice. A Born-Mayer expression is used for the interionic potential function, and during the relaxation of the positions of the central ion rows all rows outside these are held fixed in the positions calculated by elastic theory. The numerical results indicate that this last restriction can lead to physically unrealistic results. Values for the relaxation displacements and energy changes will be presented.

* To be given at the end of Session Z if the Chairman rules that time permits.
† Research supported in part by the Air Force Office of Scientific Research.
‡ Now at the University of Maryland.

SP4. dc Electroluminescence of Powder Phosphors. W. A. THORNTON, *Westinghouse Electric Corporation.**—Although much work has been done with ac electroluminescence of zinc sulfide type powder phosphors (see the review of reference 1), the only reported work on dc electroluminescence of zinc sulfide involves single crystals,[2-4] and the information published in fragmentary. All strongly ac electroluminescent sulfide-type phosphors examined, and many "nonelectroluminescent" phosphor powders, show dc electroluminescence in conventional phosphorplastic dispersions with high phosphor-plastic weight ratios. Some phosphors show marked spectral differences between ac and dc electroluminescence. In one case both ac and dc electroluminescence follow the function $\log L \propto (-A/V^{\frac{1}{2}})$ although with different A; the plots appear to intersect at infinite voltage. The dependences of dc electroluminescence on field, temperature, and phosphor type will be described.

* To be given at the end of Session VA if the Chairman rules that time permits.
[1] G. Destriau and H. F. Ivey, Proc. Inst. Radio. Engrs. **43**, 1911 (1955).
[2] W. W. Piper and F. E. Williams, Phys. Rev. **87**, 151 (1952).
[3] R. W. Smith, Phys. Rev. **100**, 760 (1955).
[4] G. F. Alfrey and J. B. Taylor, Proc. Phys. Soc. (London) **B68**, 775 (1955).
[5] G. F. Neumark, Phys. Rev. **103**, 41 (1956).

Author Index to Papers Presented at the Washington Meeting

Adair, Robert K.—V12
Adelson, Harold E.—L1, L2
Albers, W. A., Jr.—VA15
Albridge, R. G.—J7
Alder, B. J.—Z1
Alexander, J. M.—RA11
Alford, W. Parker—R6, R8
Almqvist, E.—P5
Amado, R. D.—WA12
Ammar, R. G.—EA3, EA4
Anderson, James L.—D5
Anderson, Kinsey A.—W9
Anderson, Roy S.—FA6
Andresen, Arne—L8
Arakengy, Albert—LA13
Arditi, M.—J2
Armstrong, Alice H.—A12
Arnoldy, R.—W13
Ashkin, J.—NA8
Atkinson, John H.—L3
Baerg, A.—E11
Baker, S. I.—E2
Baldo-Ceolin, M.—A11
Ballam, J.—NA9, NA10
Banzhaf, J.—VA2
Barber, W. C.—E7
Barkow, A. G.—A3
Barnes, S. W.—NA7
Barschall, H. H.—B6
Barth, C. A.—U12
Bartholomew, G. A.—B8, T7
Bashkin, S.—P2, P3
Bay, Z.—Y9
Beard, David B.—W15
Beaty, Earl C.—J3
Bedo, D. E.—LA7
Beers, Yardley—U3
Bég, M. A. B.—Y1, Y4
Beghian, L. E.—G10
Beiser, A.—W2
Bell, R. E.—GA1
Bender, P. L.—J9
Bender, Peter L.—J3
Benedek, G. B.—BA7
Benenson, R. E.—P6
Bennett, F. D.—TA1
Bennett, W. R., Jr.—U14
Bent, R. D.—P11
Bergmann, Peter G.—H12
Berners, E. D.—R1
Beth, R. A.—C8
Bieri, Rudolf H.—W12
Bilaniuk, O. M.—K8
Bilpuch, E. G.—B2, B3
Bingham, H. H.—NA6
Birkhoff, R. D.—G9
Bishop, M. E.—F13
Bjorkstam, John L.—BA4
Blanpied, W.—R5
Bleuler, E.—P8, P9
Block, R. C.—F9, F11, F12
Blosser, H. G.—G2, SP1
Boardman, John—H12
Bockelman, C. K.—F8
Bodansky, D.—K12
Boehm, Felix—R10
Bohm, H. V.—X6
Boldt, E.—A6, A10, EA2
Bollinger, L. M.—F7
Bondelid, R. C.—CA2
Bostick, Hoyt A.—L1, L2
Bowman, C. D.—B3
Bradley, Richard C.—LA12, LA13
Braid, T. H.—K11
Bramley, A.—Z8
Braslau, N.—J1
Braustein, R.—VA6
Bray, P. J.—BA8, BA9, BA10, FA2
Breit, G.—H2, H3
Bridge, H.—A6, A10, EA2
Brink, Gilbert O.—J1, J6
Brockhouse, B. N.—LA9, M12, SP2
Brody, H. M.—A9
Bromley, D. A.—P5, GA4
Broude, C.—P2, P3
Brout, R.—PA7
Brown, F.—E11
Brown, G. E.—E1, DA1
Brown, L. Carlton—BA5, BA6
Brown, Laurie M.—D7
Brown, R. J. S.—BA2
Broyles, A. A.—PA2
Brugger, K.—X9
Brussel, M. K.—F6
Burford, A. O.—S3
Burgers, J. M.—AA2
Burson, S. B.—M6, RA10, S6
Butler, J. W.—CA3
Byram, E. T.—W14
Cable, J. W.—M7
Caldwell, D. O.—A6, A10, EA2
Call, R. L.—A4, A5
Callaway, Joseph—LA6
Camac, M.—NA11
Cameron, A. G. W.—XA1
Cameron, J. R.—K6
Campion, P. J.—T7
Cantor, Arnold J.—PA11
Capps, Richard H.—G5
Carlson, R. R.—P2, P3
Carpenter, R. T.—L6, F7
Carroll, E. E.—E8
Carter, R. E.—XA7, XA8
Cartwright, D. R.—RA7, RA8
Casabella, P. A.—BA8, BA10
Chagnon, P. R.—RA5
Chen, Sheau-Wu—K14
Chiu, H. Y.—NA13
Chrien, R. E.—F6
Christian, R. H.—Z1
Chubb, T. A.—W14
Church, E. L.—H9
Clauser, F. H.—AA1
Clegg, A. B.—NA6
Clikeman, F. M.—S2
Cline, J. E.—RA5
Cocconi, G.—Y7
Cocconi, V. T.—Y7
Cohen, Anna Foner—X10
Cohen, Bernard L.—T9
Cook, C. F.—L4
Corelli, J. C.—P8, P9
Cormack, A.—R3, R4
Coryell, C. D.—RA11
Costello, D. G.—V11
Cranberg, L.—B5, E4
Crew, J. E.—NA2
Crewe, A. V.—NA1
Crittenden, R. R.—NA9, NA10
Curtis, R. B.—C9
Cutler, W. G.—Z13
Dabbs, J. W. T.—G7
Dahler, John S.—PA5
Daitch, P. B.—L7
D'Arcy, R. A.—W3
Daunt, J. G.—X9
Dauphinee, T. M.—G12
Davis, J. R.—VA7
De Dominicis, C.—WA10
de Launay, J.—M10
Delbecq, C. J.—FA4
dePackh, D.—G3, G4
Derr, V. E.—U5
Dessler, A. J.—X2
Deutch, B. I.—S10
de Zafra, Robert—Y3
Diesel, T. J.—Z9
Dillon, J. F., Jr.—M3
Dobrov, W. I.—Z9
Dodge, W. R.—E7
Dolecek, R. L.—M10
Domanic, Fahri—F10
Donahue, T. M.—Y10
Douglas, R. A.—P2, P3
Douthett, Doane—X8
Dransfeld, K.—X1
Draper, J. E.—F8
Dresden, M.—H10
Dropesky, B. J.—RA12
Eastwood, T. A.—S4
Eccles, S. F.—K12
Egan, W. G.—M4
Eichler, E.—RA9
Eisberg, R. M.—T13
Eisenhauer, C. M.—LA8
Eisenstein, J. C.—Q4
Eisinger, J.—LA14
Elleman, Daniel D.—BA5
Elliot, David—NA5
Elliott, S. D., Jr.—X3
Elwyn, A. J.—T5
Emmons, L. B.—V6
Enge, H. A.—T4
Evans, D.—A7, A8
Ewbank, Wesley B.—J4, J6
Eyges, L.—D13
Fairbank, Henry A.—X3
Fairbank, W. M.—U2
Fairbank, William M.—BA1
Feher, G.—FA12
Fenton, A. G.—W6
Ferguson, J. M.—T2
Ferrell, R. A.—RA3, X12
Ferrell, Richard A.—LA3, LA4, LA5, PA9, PA12
Feshbach, Herman—H6
Fischer, C. R.—H2
Fischer, G. E.—P4
Fischer, V. K.—P4
Fisher, David E.—XA5
Fisher, P. S.—S9
Fluharty, R. G.—F2, F3
Foland, W. D.—WA11
Foner, Simon—M2

Fox, J. D.—F6
Freier, P. S.—W7
Frerichs, R.—VA14
Fried, Burton D.—H14
Friedberg, S. A.—X8
Friedman, H.—W14
Frye, Glenn M., Jr.—A12
Fulton, T.—H10
Furr, A. K.—B3
Gallagher, J. J.—U5
Gardner, M. E.—G11
Garfinkel, S. B.—Z11
Gärtner, W. W.—VA12, VA13
Gauthe, Bernard—LA2
Geffen, Donald A.—V4
Geiger, J. S.—S4
Geller, K. N.—C12
Gerjuoy, E.—D11
Gerstein, G.—R9
Giacomelli, G.—NA7
Gibbons, J. H.—B4, K5
Gibson, W. A.—V6
Gildart, Lee—VA7, Z10
Gilfert, James C.—U11
Girifalco, L. A.—LA15
Glasoe, G. N.—T5
Glick, Arnold J.—LA4
Godlove, T. F.—G4
Goldberg, E.—XA4
Goldberg, H.—FA15
Goldberg, Irwin—D8
Goldberg, N.—S10
Goldemberg, J.—E10
Goldman, D. T.—RA3
Good, R. H., Jr.—D4
Good, W. M.—B4
Gordy, Walter—FA7, FA8, FA9
Gove, H. E.—P7, P12
Graham, R. L.—S4
Green, M.—VA2
Greenberg, I. N.—VA2
Greenberg, J. Mayo—D12
Greider, Kenneth R.—WA5
Grench, H. A.—RA10
Griffiths, R. J.—T13
Grilli, M.—A7
Grover, R.—Z1
Guerriero, L.—A7
Hall, R. C.—M9
Halpern, J.—C12
Hamburger, A. I.—K4, WA2
Hamburger, E. W.—K4, WA2
Hamilton, J.—NA12
Hamilton, J. H.—S5
Hammer, C. L.—D4
Hammer, Charles L.—G1
Handy, R. M.—VA14
Hanna, S. S.—K10
Harrison, B. K.—C9
Harrison, P.—Z3
Harrower, G. A.—KA1
Hart, E. L.—Y7
Harvey, J. A.—F9, F11, F12
Hassan, F.—A7
Hayes, W.—FA4, FA5
Haynes, S. K.—S3
Heath, R. L.—S11
Hedgcock, F. T.—M11
Helmy, E.—A7
Henkes, W.—S1
Henry, Warren E.—M8
Hensel, J. C.—K8
Henshaw, D. G.—X4
Herzfeld, C. M.—FA14, FA15
Hess, D. C.—Z12
Hess, Wilmot N.—L3
Heydenburg, P.—P10
Hill, R. D.—NA2
Hintz, N. M.—GA2
Hoffman, John H.—W11
Hoffman, R.—W13
Holladay, Wendell G.—V8
Holland, R. E.—T3
Hommel, M.—LA11
Hooke, William M.—J8
Hooper, H. O.—BA9
Hough, P. V. C.—G8
Hubbs, J. C.—J7
Hudson, E. D.—SP1
Hughes, D. J.—F1, F6, LA8
Hughes, V. W.—Y5, Y6
Hull, M. H., Jr.—H2
Imhof, W. I.—B7
Irwin, F.—G2
Iyengar, P. K.—LA9, M12
Jastrow, R.—KA2
Javan, Ali—U1
Jeffrey, G. A.—Z3, Z5
Jensen, J. H. D.—DA2
Johansson, Sven A. E.—E12
Johnson, C. M.—U5
Johnson, N. R.—RA9
Johnson, R. G.—B8
Johnson, T. E.—Z10
Johnson, W. B.—NA11
Johnsrud, A. E.—B6
Johnston, Lawrence H.—CA4, R2
Jones, F. E.—Z11
Jones, J. T., Jr.—V11
Jones, K. W.—P6
Jones, Lawrence W.—C2, C3
Jorgensen, Theodore, Jr.—Y8
Jungerman, J. A.—G11
Juretschke, H. J.—M4
Kane, G.—A3
Kane, John V.—S8
Kaplan, J.—U12
Kaplan, R.—FA2
Karp, Ira L.—PA10
Karp, S. N.—H11
Kasner, W. H.—Y10
Katz, L.—E11
Kawaguchi, Masaaki—V9, WA1
Keffer, F.—M1
Kegel, G. H. R.—G10
Kelley, J. W.—T4
Kenemuth, J. R.—LA11
Kennedy, Anthony—X11
Kennett, T. J.—F7
Kenney, Robert W.—NA4
Kern, B. D.—K2, K13, T2
Keuffel, J. W.—A4, A5
Keyes, Robert W.—U10
Khan, J. M.—J1
Kidder, J. N.—U2
Kim, Y. B.—W1
Kim, Y. W.—FA2
King, R. W.—RA1
Kjeldaas, T., Jr.—FA13
Klein, Abraham—D3
Klein, L.—U13
Knapp, Edward A.—NA4
Knecht, David J.—R1
Knowles, J. W.—T7
Koch, H. W.—E9
Koehler, W. C.—M7
Kokoszka, F. T.—RA8
Korff, S. A.—W2
Kowalski, S.—E11
Kraus, O.—BA3
Kreger, W. E.—K2, K13
Kruse, Paul W.—VA4
Kruse, T. H.—P11
Kruse, U. E.—NA1
Krusemeyer, H. J.—VA8
Kuehner, J. A.—P5
Kunze, J.—NA8
Kupperian, J. E., Jr.—W14
Kurbatov, J. D.—RA7, RA8
Kushida, T.—BA7
Kuyatt, Chris—Y8
Lampert, M. A.—VA9
Landon, H. H.—T5
Langer, L. M.—S5
Langsdorf, A., Jr.—G6
Larson, H. V.—Y11
Lasky, C.—C8
Laslett, L. Jackson—G1
Laurie, Victor W.—U6
Lawson, R. D.—WA6
Lax, B.—VA5
Lebowitz, Joel L.—PA8
Lederman, L.—Y5
Lee, L. L., Jr.—K9, T8
Lee, T. D.—MA2
Levin, J. S.—B5
Levine, D. B.—FA14
Levi-Setti, R.—EA3, EA4
Levitt, Leonard S.—EA1
Lewis, H. R.—FA11
Lichten, William—J5
Lichtenstein, P. G.—G11
Lide, David R., Jr.—U7
Lidofsky, L. J.—P11
Lilliequist, C. G.—C4
Limentani, S.—EA3, EA4, EA5
Lindenbaum, S. J.—V3
Lipson, H.—VA5
Litherland, A. E.—P7, P12
Littlejohn, C. S.—XA3
Lockwood, John A.—W5
Lomon, E.—H1
Lord, R. S.—SP1
Lowe, J.—T10
Lu, D. C.—S2
Lundy, R. A.—NA14, NA15
Lupton, W. H.—LA5
Lurio, A.—Y5
Lynch, F. J.—G6, T3
Lynton, H.—Z5
Macdonald, J. Ross—VA10
MacDonald, W. M.—CA1
Macklin, R. L.—K5
MacQuarrie, R. A.—Z11
Malik, S. S.—S7
Malone, D.—Y5
Mandelstam, S.—V5
Mandeville, C. E.—B11, S7
Mann, A. K.—E13
Mann, D. P.—F4

Manning, G.—B8, T7
Maradudin, Alexei—Z14, Z15, SP3
Marcus, Paul M.—X11
Margenau, Henry—U13
Marino, Lawrence L.—J4, J6
Marion, J. B.—B5
Mark, Hans—GA3
Marques, L.—E10
Marrus, R.—J7
Marshak, R. E.—DA3
Martin, D. W.—M6
Martin, Paul C.—PA6, PA11, WA10
Maximon, L. C.—E14
McColm, D.—Y5
McCormick, Gene—FA7
McCormick, William D.—BA1
McDaniel, R. E.—A3
McDermott, L. C.—P6
McDermott, Mark—J5
McDonald, Frank B.—W4
McGowan, F. K.—XA10
McGruer, J. N.—P1
McIntosh, J. S.—WA7
McReynolds, A. W.—L8, L9
McVoy, Kirk W.—WA14
Mead, C. Alden—D6
Meier, Homer K.—C6
Meissner, Hans—X5
Mendlowitz, H.—LA1
Merkel, George—T12
Merlin, M.—A7
Messelt, S.—R1
Mette, H.—VA12, VA13
Metzger, F. R.—K3
Meyer, Peter—W8
Meyer-Schützmeister, Luise—K10
Michel, R. E.—FA11
Miller, John H., III—RA6
Millett, Walter E.—B9
Mills, F. E.—C7
Mills, Fred E.—C2
Miyagawa, Ichiro—FA8
Miyake, K.—NA7
Mizushima, Masataka—U9
Moore, W. E.—P1
Moore, W. H.—T4
Moravcsik, Michael J.—V1
Morgan, Ira L.—B10
Moroi, D.—H10
Morrison, G. C.—XA3
Morse, R. W.—PA13, X6
Moyer, Burton J.—L1, L2
Mozley, R. F.—NA3
Muirhead, E. G.—C12
Mulvey, J. H.—A7
Murray, J. J.—EA7
Myers, R. D.—LA5
Nagpaul, K. K.—A7
Nath, N.—B11
Nath, Narenda—S7
Nathans, R.—Z4
Nauenberg, M.—PA7
Naumann, R. A.—S9
Need, John L.—T6
Neiler, J. H.—B4
Newson, H. W.—B1, B2, B3
Ney, E. P.—W7
Nichols, G. M.—FA5
Nichols, H.—V10
Nichols, P. F.—B2, B3
Nicholson, A. F.—E1
Nier, A. O.—W11
Nierenberg, W. A.—J4
Nigam, B. P.—H5
Noble, Gordon A.—FA3
Nolan, J.—Y10
Northcliffe, L. C.—R1
Obenshain, Felix E.—Y2
O'Friel, P.—A7
O'Friel, Z.—A3
Oguchi, T.—M1
O'Kelley, G. D.—RA9
Okhuysen, Pablo—B9
Oldenberg, Otto—KA4
Oleksa, S.—T5
Olsen, Haakon—E14
O'Neill, G. K.—C9, C10, D2
Orth, Charles J.—RA12
O'Sullivan, W.—Z6
Overseth, O. E., Jr.—T1
Page, Lorne A.—Y2
Pal, Yash—A6, A10, EA2
Palevsky, H.—LA8
Palfrey, T. R., Jr.—E3
Palmeira, R. A. R.—W3
Palmieri, J. N.—R3, R4
Panofsky, W. K. H.—EA6
Park, S. C.—WA7
Parker, James H., Jr.—Z7
Parks, P. B.—B1
Parratt, L. G.—LA11
Parzen, G.—C1
Patronis, Eugene T., Jr.—F10
Patten, C. G.—G11
Patten, Frank—FA7
Paul, W. J.—RA7
Peaslee, D. C.—V9
Peck, R. A., Jr.—T1, T10
Pelah, I.—L9, LA8
Percus, Jerome K.—PA3, PA4
Perez-Mendez, Victor—L3, NA4
Peria, W.—Z2
Perkins, J. F.—RA1
Perls, T. A.—Z9
Peterson, F. L.—C5
Peterson, L.—W13
Pickart, S. J.—Z4
Pinkston, W. T.—WA8
Pondrom, L. G.—NA1
Poole, Charles P., Jr.—FA6
Post, R. F.—N1
Prange, Richard—D3
Present, R. D.—WA11
Preston-Thomas, H.—G12
Priest, J. R.—P8
Proctor, D. G.—E5
Prowse, D. J.—A7, A8, A11
Prud'homme, J. T.—B10
Pruett, C. H.—C4
Pyatt, K. D., Jr.—H2
Quinn, John J.—PA9
Ramsey, N. F.—R3, R4
Raphael, R. B.—H4
Rasmussen, V. K.—K3
Rawitscher, G.—V6
Raz, B. James—WA9
Reeves, H.—XA2
Reibel, K.—E13
Reilly, E. D., Jr.—D12
Reines, F.—XA8
Rexroad, Harvey—FA9
Reynolds, H. L.—XA4
Rhodes, J. L.—E6
Ring, J.—NA7
Ritchie, R. H.—G9
Roberts, Arthur—J10
Roberts, J. H.—EA3, EA4, EA5, L5
Roberts, L. D.—G7
Roiseland, D. S.—C7
Romanowski, T. A.—NA8
Rose, B.—NA7
Rose, D. C.—W6
Rosenberg, Leonard—D10
Rosenthal, J.—U8
Rothman, M. A.—B11
Rothstein, Jerome—PA1
Royce, Barrie S. H.—VA11
Rubin, Allen G.—T9
Saenz, A. W.—Q2
Salpeter, E. E.—XA2
Sandmann, W. H.—A4, A5
Sands, Matthew—NA5
Sautter, C. A.—Y8
Sawicki, J.—WA3
Scandrett, J. H.—NA9, NA10
Schade, W. J.—U12
Scharenberg, R. P.—G10
Schein, Marcel—A1
Schiessler, R. W.—Z13
Schiffer, J. P.—K9, T8
Schindewolf, U.—RA11
Schlein, P. E.—EA3, EA4, EA5
Schmid, L. C.—M6, RA10, S6
Schmidt, Bernhard M.—BA6
Schwartz, Melvin—W10
Schwartz, R. B.—F4
Schwartz, Robert B.—F5
Schwed, P.—D9
Schwinger, J.—PA6
Seliger, H. H.—Y9
Sellen, J. M.—Y7
Sens, J. C.—NA14, NA15
Seppi, E. J.—XA6
Seth, Kamal K.—WA13
Seward, Frederick D.—P14
Shafi, M.—A7
Shafroth, S. M.—L6
Shankland, R. S.—F3
Shaw, C. B., Jr.—H8
Shephard, W. D.—NA9, NA10
Sher, Rudolph—S8
Sherman, F. S.—AA3
Sherr, R.—P13
Shiffman, C. A.—X7
Shugart, H. A.—J4, J6
Siegel, Benjamin M.—LA10
Silbert, M. G.—B6
Silsbee, Henry B.—J4, J6
Simon, Albert—N3
Simpson, F. B.—F2
Simpson, O. D.—F3
Sirlin, Alberto—V7
Slater, W. E.—EA3, EA4
Slaughter, G. G.—F9, F11, F12
Slepian, J.—G13
Smart, J. Samuel—M5
Smith, J. H.—E2, DA4
Smith, W. R.—TA3
Smotrich, H.—P6
Solow, M.—VA1

Spitzer, Lyman, Jr.—N2
Spruch, Larry—D10
Steffen, R. M.—RA2
Stehle, P.—Y1, Y4
Steinberg, P. H.—EA3, EA4, EA5
Stelson, P. H.—XA10
Stephens, W. E.—E6, E8
Stern, Edward A.—LA3
Sterne, T. E.—AA4
Sternheimer, R. M.—V3
Stewart, M. G.—S2
Stolovy, A.—F13
Stork, D. H.—A7
Strait, E. N.—L6
Strauch, K.—R9
Sugawara, Masao—V2
Sundaresan, M. K.—H5
Sutton, David C.—RA6
Swann, C. P.—K3
Swanson, R. A.—NA14, NA15
Swartz, G. A.—VA3
Sweetman, D. R.—K1, T11
Symon, Keith R.—C2, C3
Szekely, Michael E.—C11
Talley, R. M.—Q3
Tangherlini, F. R.—NA3
Tautfest, G. W.—E3
Taylor, R. E.—NA3
Telegdi, V. L.—NA14, NA15, Y6
Temmer, G. M.—P10
Templeton, L. C.—X10
Tendam, D. J.—P8, P9
Terwilliger, Kent M.—C2, C3
Teucher, Martin W.—A1, A2
Thomas, J. E., Jr.—VA15
Thompson, L. C.—L4
Thompson, R. D. F.—H8
Thompson, W. E.—T2
Thornton, W. A.—SP4, VA16
Tidman, D. A.—TA2
Tomboulian, D. H.—LA7
Townsend, J. R.—Z3
Tsai, Yung Su—R2
Tsao, C. J.—C9
Tuan, T. F.—D11
Turner, J. E.—WA7
Uehling, Edwin A.—BA4
Vanhuyse, V. J.—E7
Van Patter, D. M.—B11, T14
Vaughn, F. J.—B7
Vegors, S. H., Jr.—S11
Voelker, W. H.—E5
Vogt, E.—H7
Waddell, Charles N.—L1, L2
Waddington, C. J.—W7
Wagner, J. J.—XA7, XA8
Wainfan, N.—LA11
Walker, R. L.—A9
Walker, W. D.—NA9, NA10
Wall, N. S.—T11
Wallace, Roger—RA4
Wallace, Roger W.—L3
Wallenmeyer, W. A.—C5
Walsh, W. M., Jr.—FA1
Walt, M.—B7
Walter, F. J.—G7
Wangsness, R. K.—Q1
Warner, Robert E.—R6, R8
Warren, J. L.—X12
Wataghin, A.—A7
Watson, W. W.—F4
Webb, W.—Z13
Webb, William H.—T6
Webber, R. T.—M10
Weibel, Erich S.—H13
Weiffenbach, G. C.—U4
Weinstock, Eugene V.—S8
Weiss, George—Z14
Weizer, V.—LA15
Welch, J. A., Jr.—RA4
Weneser, J.—H9
Wergeland, Harald—E14
Weston, L. W.—B3
Wetherell, A. M.—A9
Wexler, A.—Z11
Wexler, S.—Z12
Whittemore, W. L.—L8, L9
Wigner, E. P.—D1
Wilkinson, M. K.—M7
Williams, B. D.—SP1
Williams, Dudley—BA5, BA6, U11
Williams, R. W.—W3
Williams, W.—G8
Williamson, R. M.—B1
Wilson, Richard—R3, R4
Winckler, J. R.—W13
Winder, R. O.—G8
Winhold, E. J.—E8
Wolff, M.—E8
Wollan, E. O.—M7
Woods, E. J.—C10
Wu, C. S.—U14
Wyckoff, J. M.—E9
Wyman, M. E.—K7, XA7, XA8
Yang, C. N.—MA1
Yergin, P. F.—C12
Yevick, George J.—PA3, PA4
Yntema, J. L.—K11
Yoshiki, H.—P13
Young, James E.—WA4
Yovanovitch, D.D.—NA14, NA15
Yuster, P. H.—FA4
Zapolsky, H.—LA11
Zelikoff, Murray—KA3
Zimmerman, R. L.—F1, F6
Zitron, N. R.—H11
Zwerdling, S.—VA5

Preliminary Announcement of the 1958 Summer Meeting in the East

The 1958 Summer Meeting of the American Physical Society in the East will be held on Thursday, Friday, and Saturday, June 19, 20, and 21, at Cornell University, Ithaca, New York. The Division of Electron Physics will make this meeting its principal assembly of the year, and the Division is planning a substantial programme of invited and contributed papers. Sessions of invited papers have already been arranged on upper atmosphere physics, high-energy electrons and plasmas, inelastic collisions, and parametric amplification. There will be a chicken barbecue at Taughannock Falls State Park on Cayuga Lake Thursday evening and an evening lecture on Friday. The ladies' programme will take advantage of the many parks and other attractions near Ithaca.

Individual members of either sex and couples will probably wish to be housed in dormitories on the Cornell campus, but children cannot be accommodated therein. The rates in the dormitories are $3.00 for single and $5.00 for double rooms. There are also half a dozen modern motels within a few miles of the campus with rates from $3.50 to $6.50 for single and $5.00 to $10.00 for double rooms, but the total motel space probably will be rather limited. Requests for reservations at either dormitories or motels should be addressed as soon as possible to Mr. A. L. Johnson, Department of Physics, Rockefeller Hall, Cornell University, Ithaca, New York.

Transportation to Ithaca is provided by Mohawk Airlines, the Lehigh Valley Railroad, and the Greyhound Lines. The dormitories are a few minutes walk from the meeting halls, but an automobile is necessary for residents of motels (and desirable for all).

The deadline is April 18, and abstracts are to be sent to the Secretary of the Society at Columbia University, New York 27, New York.

Preliminary Announcement of the 1958 Meeting at Vancouver, British Columbia

The 1958 summer meeting will be held on the Canadian Pacific Coast in Vancouver, British Columbia on Tuesday, Wednesday, and Thursday, August 26, 27, and 28, 1958. The sessions will be held in the Physics Building on the campus of the University of British Columbia which is situated at Point Grey about seven miles west of the center of the city of Vancouver. This year is the occasion of the 100th Centenary of the foundation of the Province, and also of the 50th anniversary of the establishment of the University.

Invited paper sessions will include the topics of high-energy physics, low-energy nuclear physics, resonance and low temperatures, solid state, and earth and cosmic physics. On Tuesday evening there will be a cruise on Burrard Inlet to demonstrate oceanographic and marine physics research equipment. The banquet will be held on Wednesday evening.

Accommodation will be available on campus in the Women's Residences at $3.00 per night per person in double rooms. There will be some accommodation for families with children in the men's temporary dormitories at Fort Camp at about $2.00 per person per night. Reservations for campus accommodation should be addressed to Dr. G. L. Pickard, A.P.S. Local Arrangements Committee, Department of Physics, University of British Columbia, Vancouver 8, B.C., Canada.

There is no hotel or motel accommodation close to the campus. Hotels in downtown Vancouver include the Hotel Vancouver (from $8.00 single, $10.50 double, $12.50 twin beds), Hotel Georgia (from $7.00 single, $10.00 double, $11.00 twin beds), and Hotel Devonshire (from $9.50 double, $10.50 twin beds). The most conveniently situated motels are those downtown, the Burrard Motel, Kamlo Motor Apartment Motel, Park Town Motel, and Downtowner Motel. The majority of the motels, however, are located along Kingsway on the southern approach to the city along Route 1/99 between New Westminster and Vancouver at 9 to 15 miles from the campus. Write to Dr. Pickard if you need a list of addressses.

Reservations at these hotels or motels should be made directly as early as possible, and at least one month before the meeting, as this is a busy season.

Vancouver is served by the Canadian National and Canadian Pacific Railways, by the Great Northern Railroad from eastern United States, and indirectly by the Southern and the Northern Pacific Railroads from south and east. Trans-Canada Air Lines and United Airlines operate to Vancouver International Airport, 10 miles south of the city center. There is limousine service between the airport and downtown. The journey from downtown to campus takes about 45 minutes by trolley coach, 20 minutes by taxi. Visitors may also embark on a Canadian Pacific Steamship in Seattle and complete their journey to Vancouver by sea. The C.P.S.S. docks are in the downtown area. Members desiring accommodation for private yachts should let the Local Arrangements Committee know in good time.

Finally, it is proposed to arrange a trip to Garibaldi Provincial Park after the meetings if a sufficient number is interested. The party would fly in (half an hour), camp for two nights, and return by train. (The camp is 4000 feet above the railway.) For the really energetic, a glacier climb up Mt. Garibaldi (8787 feet) would be planned for the middle day. Persons interested in this excursion should write to Dr. Pickard.

Deadline for abstracts of contributed papers is Friday, June 27, and they should be sent to Dr. William A. Nierenberg at the address below.

W. A. NIERENBERG
Local Secretary for the Pacific Coast
Department of Physics
University of California
Berkeley 4, California

MEETINGS AND DEADLINES FOR 1958

Place	*Meeting dates*	*Deadline date*
Washington	May 1–3	past
Ithaca, New York	June 19–21	April 18
Vancouver, *British Columbia	August 26–28	June 27
not decided	November 28–29	September 26
Los Angeles	December 29–31	October 17

* Abstracts for the Vancouver and Los Angeles meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline-day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; one must be an original, the other may be an original or a carbon copy. *They must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *If we receive an abstract typed on two pages, we print only its first page.* Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It now becomes an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

Proceedings of the American Physical Society

Minutes of the Meeting Held at St. Louis, November 29–30, 1957

ONCE in a while we displace the Thanksgiving meeting of the American Physical Society away from its most usual habitat of Chicago. When thus displaced, the meeting is never so large, but all who come have the pleasure of visiting a different place, and the place is always more convenient to some of our members though never to all. St. Louis is one of our favorites among these places, and Washington University always a skilled and hospitable host. The 1957 Thanksgiving meeting was the third to be held at that University since World War II. A registration total of 353 seemed deplorably small, in view of the excellence of the programme and the excellence of the arrangements made by the Local Committee: here we must render especial thanks to the Committee, and in particular its Chairman, John M. Fowler; Mrs. Elizabeth Zeltner the secretary of the Department of Physics; and A. H. Weber of St. Louis University who lent a parking lot to those who drove to the banquet—nor must we forget other secretaries both of Washington University and of St. Louis University who helped with the registration. Halls in four different buildings of the University were placed at our disposal: we had plenty of opportunity to enjoy the beauty of the campus in rambling from session to session. The weather ran the whole gamut from warm to cold but was never unpleasant.

There were one hundred and sixteen ten-minute papers, and it was interesting to observe that even though the Division of that name holds its principal sessions at another meeting of our Society, solid-state physics abounded so at this one that it was impossible to arrange the programme so as to avoid simultaneities between solid-state sessions. Yet the idea that ours is primarily a nuclear-physics society dies hard! Of the groups of invited papers, one pertained to superconductivity (unexpectedly the Division of Solid-State Physics also produced a Symposium on low-temperature physics), one to accelerators, one to nonconservation of parity, and one to neutron physics, a good variety!

The banquet was held in the Coronado Hotel on Friday evening, with attendance of 231—quite an unusually large fraction of the registration, and this we attribute to the fame of the after-dinner speakers: E. U. Condon, A. H. Compton, and lastly John P. Hagen of Project Vanguard, whose timely address on the problems of the satellites was followed with utmost attention.

The Council met on Saturday. It elected to Fellowship 12 candidates and to Membership 484: their names follow.

Elected to Fellowship on November 30, 1957: J. J. Brady, E. C. Campbell, J. W. Dabbs, S. E. Forbush, M. H. Foss, S. F. Friedland, Leo Goldberg, R. E. Holland, C. D. Moak, C. A. Reynolds, C. H. Shaw, R. G. Shulman, R. H. Stelson, L. C. Teng, H. B. Willard.

Elected to Membership on November 30, 1957: *Robert W. Allison, Jr., Bernard Altshuler, Elmer E. Anderson, *Gerald F. Anderson, Marvin M. Antonoff, *James C. Armstrong, Thomas Athanis, Ronald A. Aziz, Arthur E. Baldwin, Barrett S. Baldwin, Luis C. Barajas, *Marcel Bardon, Joseph G. Barredo, *Bruce E. Barnaby, *Mario E. Bauer, Richard J. Bearman, Carl H. Becker, John A. Becker, *Louis Becker, William B. Benedick, *Stewart Bennett, *John W. Benoit, *Jay L. Benson, *Barry L. Berman, *Walter J. Bertram, Jr., Robert R. Bilderback, James H. Blackburn, *J. Warren Blaker, Keith G. Blanton, Marts Donald Blue, *William E. Blumberg, Joseph E. Bogar, Henry J. Bowlden, *Clyde B. Bratton, William P. Brooks, Theodore G. Brough, Gerald E. Brown, *Richard G. Brewer, John F. Britt, *Stephen G. Brush, *Stanley M. Bunch, Milton Burton, Robert W. Byrne, *Reginald L. Call, *Graham Campbell, Johnny M. Canfield, *John A. Cape, *Peter Carruthers, *Thomas N. Casselman, Paul P. Castrucci, Mary C. Cavallaro, Moon H. Cha, Albert J. Chabai, B. S. Chandrasekhar, *Tseng-Hsu Chang, *Hopkins J. Chapman, C. E. Chase, Jr., Mark Cher, *Yanglai Cho, *Sang-Il Choi, Max Chretien, Jay V. Christensen, *John Robert Christy, Ki-Ho Chung, Ubert Cocca, Arnold A. Cohen, Robert S. Congleton, William R. Conkie, Blossom E. Cooper, *Luciano E. Coster, Robert E. Coulehan, Daniel J. Coyle, *Paul P. Craig, Charles J. Croteau, *William J. Cushman, Jr., W. Gale Cutler, Alvin W. Czanderna, *William E. Dance, Nicola D'Angelo, *Gilbert Davidson, *Howard F. Davis, *Ronald J. Deck, Carlo Del Carlo, William D. Derbyshire, Heitor G. de Souza, *Johan J. De Swart, *Roland deWit, Philip J. Dickerman, *W. Ross Doherty, Anthony R. Donfor, Jr., *James J. Drautman, Jr., Harry Dreicer, *Russell W. Dreyfus, Donald L. Eads, *Thomas J. Eisler, P. Bush Elkin, *William E. Engeler, *Earl S. Ensberg, George M. Enslow, Paul Erdos, Roger D. Erickson, *Ronald P. Espinola, Ferdinand Euler, Arthur W. Fairhall, *Stavros Fallieros, James M. Ferguson, Philip L. Finn, Leonard D. Flansburg, G. M. Foglesong, Daniel S. Fraed, *David E. Frederick, John E. Fredrickson, Arthur H. Frentrop, David C. Fried, F. G. Friedlander, *Edward A. Friedman, Jay Froman, Robert A. Fish, *John N. Frampton, *Allen N. Friedman, *Joseph F. Froechtenigt, Ralph Fullwood, *Charles J. Gallagher, Jr., James M. Galligan, *John C. Garth, John M. Gault, *Kenneth N. Geller, Rubin Gelles, Ananda Mohan Ghosh, *Alvin P. Ginsburg, *Arnold J. Glick, *A. Donald Goedeke, *Albert Gold, Sherman Golub, Edgell C. Gooden, Jr., Alvin M. Goodman, Charles L. Gravel, David C. Greene, *William D. Greenspan, Hermann P. Greinel, Milburn B. Grier, *Charles W. Haas, Theodore A. Haddad, *Richard L. Hahn, *Yukap Hahn, Richard Robb Hake, Lawrence G. Hall, Walter Jay Hamer, *Gordon Leon Hammond, *Louis N. Hand, John R. A. Handschy, John C. Hansen, Charles E. Harrington, Joseph D. Harris, *B. Kent Harrison, William J. Harrold, *Jerome L. Hartke, Neal Hartmann, Jerry R. Havill, William Trent Hayes, Jonathan Hazoni, Lawrence A. Heinrich, Robert E. Hendricks, Thomas J. Hendrickson, Tom A. Hendrickson, Carl J. Herrlander, *Warner Hirsch, Harley C. Hitchcock, *James L. Hobart, *Russell K. Hobbie, *Myron Hochheiser, Jean Amédée Hoerni, Richard E. Holladay, Alan E. Holley, *Fred Holmstrom, Richard W. Horton, Robert E. Houston, *John A. Howe, *W. Marshall Hubbard, Jr., Jerome Hudis, *Elisha R. Huggins,

*David G. Hummer, *William E. Humphrey, James A. Ibers, *Carl K. Iddings, *Karl H. Illinger, Nicolas Inchauspe, *K. P. Jacob, E. H. Jacobsen, Henry A. Jay, *Keith B. Jefferts, *Edgar W. Jenkins, *Forrest C. Jobes, Jr., *Arne Johansson, Edward O. Johnson, Richard F. Johnson, *Robert C. Johnson, J. T. Jones, Jr., Arthur K. Jordan, George A. Kahn, *Ivan P. Kaminow, *Carrol A. Kamradt, Helmut Kanter, *Joseph E. Kasper, *Thomas S. Katman, Paul Kehler, *Richard A. Keller, *Timothy G. Kelley, Thomas Kelsall, Nicola N. Khuri, *Priidu Kiive, *Chung-hum Kim, William T. King, *Paul R. Klein, John D. Knapton, John R. Knight, Tadanobu Kojima, Arthur B. Komar, Joze Kostelec, Leslie S. G. Kovasznay, Gus C. F. Krayer, *James J. Krebs, Martin C. E. Kretzschmar, *John L. Kroening, Paul H. Krupenie, Robert W. Kulterman, Theo. J. Mayer-Kuckuk, *Richard J. Kurz, Asao Kusumegi, James J. Lander, *Ludwig J. Landgraf, Robert C. Langille, *Benjamin W. Lee, Robert A. Lefever, *Richard G. Leffler, Pierre Lehmann, *Olaf S. Leifson, *James U. Lemke, *Bobby E. Leonard, James C. M. Li, Thomas Limperis, George K. Lindeberg, Robert H. Lindquist, Sanford Lipsky, *Marvin M. Litvak, Zung-nyi Louise Loh, *Thomas A. Longo, *Rodney Loudon, Martin S. Lubell, Bruno F. Ludovici, Howard C. Ludwig, *David W. Lynch, *Victor A. Madsen, *William Malkmus, *Daniel P. Mann, *Seymour Margulies, Wayland C. Marlow III, Yoshinobu Matsukawa, Masahiko Matsumoto, Bruce R. McAvoy, James D. McClelland, *Douglas W. McColm, Charles W. McCombie, *Lillian C. McDermott, L. D. McGlauchlin, *William D. McGlinn, Juan A. McMillan, Wayne H. McQuerry, Chester A. Mead, James E. Meinhard, *N. David Mermin, Herbert L. Mette, *Donald T. Meyer, *August Miller, Richard F. Mills, Joseph A. Minahan, Miriam T. Minamoto, William Moffitt, Louis Monchick, Harold C. Montgomery, R. G. Moore, Jr., *Thomas A. Morgan, Kin-ichi Moriguchi, Harold S. Morton, Jr., Clifford J. Mosbacher, Jr., Saul Moskowitz, Rolf K. Mueller, John W. Nagle, Nelson R. Nail, Ryuzo Nakasima, *Norman C. Napier III, Hajime Narumi, *Aharon Nir, A. Paul Ofiesh, Stanley M. Ohlberg, Yasuo Oishi, Robert F. O'Keefe, Roy Elmer Olson, Rudi S. B. Ong, Horace A. Ory, *William L. Pak, Jacques I. Pankove, *Shim Choon Park, *Roy A. Parker, Jerry Kent Parks, William Paul, Joseph A. Pesch, Norman E. Phillips, Robert A. Piccirelli, Clarence R. Pierce, Arthur H. Pierson, Walter T. Pimbley, Edward L. Pipkin, *Ernest E. Pittelli, Henry H. Plotkin, Paul Polishuk, Arthur M. Poskanzer, *Martin Posner, Joseph E. Powderly, *John L. Prather, *Buford Price, Jr., J. Thomas Prud'homme, *Robert D. Puff, Peter D. Raft, Anant Krishna Ramdas, Joaquin A. Ramierz, *Rajat Kumar Ray, William G. Read, Benjamin Reed, *Paul J. Regenburger, Herbert K. Reich, Warren L. Reynolds, Charles S. Robertson, Jr., Douglas H. Rogers, *Kendal T. Rogers, *Peter Roll, Robert J. Romagnoli, *Elhanan E. Ronat, Peter Rosen, Leonard Rosenberg, *Richard W. Rothery, Laurance E. Royt, Wolfgang Ruppel, James T. Russell, *John J. Russell, *Om Prakash Rustgi, Arthur J. Samuells, *James Richard Stanford, Abdul R. Sattar, Andrej Sauer, Shozo Sawada, Dwight Proffer Saylor, George E. Schafer, John W. Scholmeier, *George L. Schrenk, Arnold W. Schultz, Richard H. Schwendeman, *Bruce L. Scott, Michael J. Scotto, Donald M. Scruton, *Manfred I. Seegall, *J. Leland Seely, Isadore Shapiro, Bohdan Shepelavey, *Mikio Shimizu, Tsuneto Shimose, Marcel R. Shmorak, *Agam Prakash Shukla, William Arthur Sibley, *Rein Silberberg, Gustavus J. Simmons, William T. Simpson, *James B. Smathers, Apollo M. O. Smith, *Raymond C. Smith, Samuel L. Smith, *Sandra Ruth Smith, Thomas Smith, *Vedene H. Smith, Warren G. Smith, William R. Snow, *Howard A. Snyder, *Alfred K. Spiegler, Charles L. Stephens, Jr. Malcolm F. Steuer, Raymond W. Steveuson, *Rae F. Stiening, Richard W. Strayer, *Stewart J. Strickler, Robert P. Stromberg, *Kiu Suk Suh, Swaminatha Sundaram, Sho Tanaka, Hamburg Tang, *Yau Chien Tang, Smio Tani, Lindsay J. Tassie, Kenneth J. Tauer, Edward J. Taylor, John G. Taylor, Nobuzo Terao, *Ernest A. Thieleker, *Eugene D. Thomas, Moody C. Thompson, Jr., *W. Paul Thompson, Jr., *William S. Thompson, *Gunnar Tibell, William E. Tiller, Frank L. Tobey, Jr., Marion N. Todd, Jr., Robert N. Thompson, William G. Trawick, Tom T. True, *T. Laurence Trueman, Georg Trumpy, *Albert Tuchman, *Jack D. Ullman, Bjarne E. Ursin, *Roger S. VanHeyningen, *John W. Verba, Franciscus P. G. Valckx, Hermanus J. Van den Bold, Jim Y. Wada, *Michael A. Wahlig, *John P. Waldron, Ronald E. Walker, *Duane C. Wallace, *William Wallace, Harvey A. Wallskog, *Maurice C. Walsted, *Robert E. Warner, Thomas C. Watson, Donald R. Wenkhous, Alan M. Wetherell, Albert L. Whetstone, Donald R. Whitman, Charles R. Whitsett, Hans Widmer, Harvell P. Williams, *Robert J. Wilson, Roderick W. Wilson, Donald E. Woessner, *How-sen Wong, John R. Woodhull, Joseph F. Woods, *George B. Wright, Daniel A. Wycklendt, *Hiroshi Yamamoto, *Richard K. Yamamoto, *S. Steven Yamamoto, Hsun-Tiao Yang, Edward C. Yates, Roy Yee, M. Dean Yeaman, Harold E. Yingst, Akihiko Yokosawa, Yusuf A. Yoler, Jerrold M. Yos, *Kwang Yu, Herbert P. Yule, *Norman J. Zabusky, Joseph F. Zechmeister.

Additional names—Candidates for membership: Milo V. Anderson, *Walter E. Carey, Richard McC. Collier, *Richard Coren, *Anthony J. DiStefano, *Vincent J. Falcone, Jr., *James A. Gaidos, Lee R. Gallagher, Paul N. Gillon, Mary L. Harbold, *Herman H. Hobbs, *William P. Kovacik, *James S. Langer, *Maurice Machover, *K. T. Mahanthappa, Hansjorg Oser, *Jack C. Overley, Roy W. Rice, *Richard M. Schectman, Edward Simon, *E. Leo Slaggie, *Prakash C. Sood, *Joseph L. Snider, Derek A. Tidman.

Errata Pertaining to Abstracts G2, N5, and Q2 of the 1957 St. Louis, Missouri, Bulletin (Series II, Volume 2, No. 7)

G2, by B. Luyet and G. Rapatz. In line 1, the first author's name should read "B. Luyet."

N5, by Gordon Ray Harrison and Cyril D. Curtis. In line 5, "deuteron energies of $E_d=0.295$, 0.260, 0.215 Mev" should read "deuteron energies of $E_d=0.270$, 0.235, 0.190 Mev." In line 7, "$E_d=0.175$ Mev" should read "$E_d=0.158$ Mev."

Q2, by Edward H. Kerner. The displayed equation, "$\int^{-\lambda t}$" should read "$e^{-\lambda t}$" and "$\int^{\lambda t}$" should read "$e^{\lambda t}$."

Minutes of the Winter Meeting on the West Coast Held at Stanford University, Palo Alto, California, December 19, 20, and 21, 1957

THE 1957 Winter Meeting on the West Coast of the American Physical Society was held at Palo Alto, California, on Thursday, Friday, and Saturday, December 19, 20, and 21. This has been one of the favorite meeting places of the Society, and it is not surprising, therefore, that a new record was set for attendance. It was a very busy week for physicists, because of the meeting on Nuclear Sizes that took place immediately before and whose last day, in fact, coincided with the first day of the meeting of the Society. It was a special occasion in that it represented the first major use of the beautiful new Physics Auditorium Building. This building represents a great addition to physics on the West Coast, and we hope that the Society will be privileged to use it in the future.

There were 27 invited papers and 149 contributed papers, and very few of the contributed papers were read by title. A special session on biophysics was held on Saturday morning of the meeting. The Society owes a good deal of thanks to Professor H. S. Kaplan of the Stanford Medical School for arranging this session.

The statistics are as follows:

The APS registration figure was 856.
The banquet attendance was 325.

We were fortunately able to arrange a cocktail party before the dinner and serve wine at the dinner as well. The presiding officer at the banquet was Professor L. I. Schiff, Executive Head of the Department of Physics at Stanford. The principal speaker was Dr. W. Shockley, who spoke on "Physicists, Dollars and Sputnik." Dean William C. Steere greeted the Society on behalf of President Wallace Sterling.

Our local chairman for the meeting was Professor S. D. Drell, who is entitled to enormous credit for handling the largest crowd of physicists yet seen at a West Coast meeting.

W. A. Nierenberg
Local Secretary for the Pacific Coast
Department of Physics
University of California
Berkeley 4, California

Errata Pertaining to Abstracts C9, M4, N1, and R12 of the 1957 Stanford, California, Bulletin (Series II, Volume 2, No. 8)

C9, by W. W. Robertson and S. E. Babb, Jr. A footnote should be added, reading: "This work was supported by the Air Force Office of Scientific Research, Air Research and Development Command, Contract A.F. 49(638)-35, Project No. 19750."

M4, by R. J. Silva, B. G. Harvey, and W. H. Wade. The name of S. Amiel should be added to the list of authors. A footnote to Dr. Amiel's name, reading: "On leave from the Israel Atomic Energy Commission, Weizmann Institute of Science, Rehovoth, Israel," should also be added.

N1, by W. T. Ogier, R. L. Wild, and J. C. Nickel. In line 7 instead of "$I=5tI_0\exp(\cdots$" read "$I=(1/5)tI_0\exp(\cdots$."

R12, by B. D. Kern, V. P. Kenney, and G. Brunhart. In line 10, instead of "6.2, 4.0, 4.4," read "6.67, 4.62, and 4.59."

Minutes of the 1958 Annual Meeting

THE 1958 Annual Meeting of the American Physical Society was held according to precedent in New York City on Wednesday, Thursday, Friday, and Saturday, January 29, 30, 31, and February 1. The precedent of holding our scientific sessions mainly in the Hotel New Yorker is now five years old: this year we had the Joint Ceremonial Session in Manhattan Center and some of the solid-state physics sessions in the Governor Clinton Hotel, which did not appear to be too remote for convenience. The precedent of extending the meeting over four days is now three years old, and we hope never to have to recompress the programme into three. The precedent of a Local Committee headed by S. A. Korff and Arthur Beiser is five years old, and we hope it will not be broken for a long time to come. We mention that every session was attended by someone who had the mission of seeing that all went well, and this someone was always a senior or graduate student of New York University.

The precedent of invoking the aid of the American Institute of Physics in handling the manifold work that has to be done before and during and after the meeting dates back to the time when we still held the Annual Meetings at Columbia University, and the sought-after aid has always been most generously and lavishly afforded, but we are

bidden not to mention names. On this occasion the aid was even ampler than heretofore, for the registration attained 3314, a figure surpassing last year's by a hundred and dropping only three hundred short of that of the incomparable 1956 event which was a joint meeting of all five of the Founder Societies of the Institute. This of course was also a joint meeting with the American Association of Physics Teachers, a precedent as old as that Association; the registration is to be credited to it in part, but we do not know what part.

At the Joint Ceremonial Session held on Thursday afternoon, H. D. Smyth delivered his Retiring Presidential Address "Past and present relations of science and government in the United States." The rest of the programme of this session, provided by AAPT, consisted of the presentation of the Oersted Medal of that Association to J. W. Buchta; of Buchta's response under the title "A new era in science?" and of P. Morrison's Richtmyer Memorial Lecture called "The approximate nature of physical symmetries." At the banquet of the two Societies held on Friday evening, there were 443 to listen to the after-dinner speeches of the Special Assistant to the President of the United States, J. R. Killian, Jr., and of the new Director of the American Institute of Physics, Elmer Hutchisson. This was a larger attendance than usually comes to honor our distinguished after-dinner speakers. At this banquet also, the Oliver E. Buckley Solid-State Physics Prize, sixth of the sequence, was presented to N. Bloembergen.

There were 367 ten-minute papers, as against 376 last year. (It continues to be the case that both the New York and the Washington meetings fluctuate little, that the former has the greater attendance and the latter the greater number of ten-minute papers.)

Observations at this convention led to the conclusion, both amusing and annoying, that often among six halls in simultaneous use the only one that will be too small is the largest! The Grand Ballroom was packed with sitters and standees for the sessions of invited papers on high-temperature plasma and on theoretical physics, and almost as much so when we moved to it from a smaller room the invited paper on structure in neutron and proton. Occasionally a room is overcrowded for an invited paper, and immediately becomes more than ample when the ten-minute papers supervene. It is clear that we shall not be able to adjust the halls perfectly to the audiences until someone invents the expansible and collapsible room.

At its meeting held on Tuesday, January 28, our Council ratified the amendments to the Constitution and By-Laws of the American Institute of Physics, propounded by that Institute and submitted some months ago to the five Founder Societies. Our ratification, being the fourth among the five, was the one that put the changes over, and the Institute considers that its new Constitution and By-Laws went into operation forthwith. The Council elected to the Governing Board of the Institute, as two of our representatives thereon, G. E. Uhlenbeck for a term of three years and H. D. Smyth for a term of one year: our other three representatives, who hold over, are H. A. Bethe, R. T. Birge, and S. A. Goudsmit. The Council named the Chairman and other members of the 1958 Nominating Committee: these names will be found on page 247 of this Bulletin. The Council authorized the establishment of a new journal of the Society, of which more shortly will be heard from the Managing Editor. Fourteen candidates were elected to Fellowship and 283 to Membership in the Society: their names appear at the end of these minutes.

At the Business Meeting of the Society, held on Wednesday afternoon, there was the usual scantness of attendance, for which the officers can console themselves only by reflecting that there cannot be anything very wrong with the Society when no one comes to set it right. These results of the recent election were announced by the Chairman of the Board of Tellers (M. W. Zemansky). Of the six whom the Nominating Committee had chosen to compete with one another for the two posts on the Council for terms running from 1958 to 1961, the two Californians, W. A. Fowler, and Charles Kittel, outran the others, but it was no landslide, the third candidate coming within 10% of the second and the last having more than half as many votes as the leader. We should have had to have a run-off election at the Business Meeting but for the timely passage of the constitutional amendment most recently submitted, which was adopted by a landslide vote. It will be printed in the new Membership List, together with the names of all present officers of the Society. The others elected on this occasion were: J. W. Beams to be President, G. E. Uhlenbeck to be Vice-President, S. L. Quimby and K. K. Darrow as heretofore to be Treasurer and Secretary, respectively: and to the Board of Editors P. G. Bergmann, Melvin Lax, F. E. Low, Maria Goeppert-Mayer, A. H. Snell, J. W. Stout, Jr., (the foregoing with special assignment to *The Physical Review*) and D. R. Inglis and P. Morrison with special assignment to *Reviews of Modern Physics*.

Elected to Fellowship on January 28, 1958: Lawrence Cranberg, James W. Davisson, A. J. Dekker, Andrew J. Drummond, Earle C. Fowler, Francis B. Harrison, Clifford V. Heer, Bernard A. Lippman, Francis E. Low, Austin D. McGuire, Arthur S. Nowick, Gilbert N. Plass, R. M. Thaler, Kenichi Watanabe.

Elected to Membership on January 28, 1958: •Edward Abramson, •William H. Adams, Jr., Arthur L. Aden, Frederick G.

Allen, Thomas L. Allen, *Silverio P. Almeida, Nissim Almeleh, *Louis W. Anderson, Marvin M. Antonoff, Anthony M. Apicella, Jr., *John Berry Ashe, Stanley B. Austerman, J. G. Barredo, Robert W. Balluffi, Hans E. Band, Rinehart Baron, William H. Barrie, Shepard Bartnoff, *Rudolf W. Bauer, *Kyle D. Bayes, *Gerhard Beckhoff, *Clyde J. Bergeron, Jr., Joseph Berkowitz, George W. Bethke, Jr., Bruce L. Blanks, Julien L. Bok, Marjorie E. Boyd, *Norman Braslau, *Charles N. Bressel, *Dale Marius Brown, Thomas H. Brown, Daniel C. Buck, Ronald E. Bullock, Martin L. Burns, Jr., Eduardo R. Caianiello, *James F. Campbell, Jr., *John Clayton Caris, Brother George Carney, *Philip A. Casabella, Gianfranco Chairotti, Clifton B. Clark, John Francis Cochran, *Roland J. Coelho, *Paul Concus, *Ronald G. Conrad, John G. Conway, *LeRoy F. Cook, Jr., James A. Cooley, Alfred W. M. Cooper, Lester M. Corliss, Lawrence E. Cotter, John P. Craven, Kermit F. Cuff, *Fred G. Cunningham, Vincent J. Cushing, Jack W. Davis, John M. Dawson, Alexander J. Dessler, Roger S. Dildine, *Lowell T. Dillman, *Roger Dittman, Leonard T. Dombras, *Willard J. Dressel, S.J., Guy Henri Dumas, James W. Dwyer, Ira Dyer, *Steve Edwards, Jr., *Richard LeRoy English, Rudolph C. Enck, Willem Euwe, Imre Farkass, Weston B. Farrand, Roberto Fieschi, *Albert C. Finn, Joseph K. Fish, J. Edmond Fitzgerald, Hugh Guthrie Flynn, Laurence Forman, Thomas K. Fowler, *Joseph D. Frascella, *Donald R. Fredkin, Graham Eugene Frye, Toyojiro Fuketa, José Fulco, *William C. Gardiner, *Marvin W. Gettner, *Giorgio M. Giacomelli, Bernard Gittelman, *Norman K. Glendenning, *José Gonzalez-Vidal, *Albert M. Gordon, *Martin Gouterman, *John Neal Green, Rolf Gremmelmaier, *Richard J. Griffiths, *Robert B. Griffiths, *John Grindlay, James R. Grover, *Harold E. Hall, John P. Hammes, C. Frederick Hansen, Kichinosuke Harada, Judson Hardy, Wallace D. Hayes, *Richard G. Helmer, *Joel E. Henkel, Joseph Hershkowitz, Martin Hertzberg, James F. Hester, Jr., Jack G. Hewitt, Jr., *Curtis K. Hinrichs, Erwin Matthias Horl, Charles M. Huggins, John P. Hummel, Robert F. Hummer, Robert L. Jameson, William R. Jewell, Richard G. Johnson, Nicholas Jouriles, *Wun Jung, *Julius Kane, *Paul H. Kasai, Akeo Kataoka, Peter Kaufman, Albert J. Keicher, Glenn H. Keitel, Claud M. Kellett, Jr., *Simon Kellman, *Jerry D. Kennedy, John E. Kilpatrick, *Louis T. Klauder, Jr., Robert Klein, Victor Lee Koirtyohann, F. Ralph Kotter, William R. Krigbaum, Reuben S. Krogstad, Klaus J. Kronenberg, M. Z. v. Krywoblocki, George C. Kuczynski, Lawrence M. Kushner, *Clare C. Leiby, Jr., Jack K. Lennard, *George E. Leroi, James M. LeTellier, Leo C. Levitt, *Moises Levy, *David B. Lightbody, Richard D. Linnell, *Richard A. Littlestone, *Leslie T. Long, Richard L. Lynn, John Macatician, John W. MacKay, Pierre C. Macq, Otfried Madelung, Geoffrey Manning, John Manton, *Lawrence L. Marino, *Ingvar Marklund, Gary D. Marshall, John H. Mathews, *Leonard F. Mattheiss, *Herbert Matthews, Charles W. Matthis, Jr., *John A. McClure, Donald E. McCrary, George M. McManus, *Gilbert D. Mead, *Robert L. Mieher, *Philip D. Miller, *Ralph C. Minehart, William R. Minrath, Dr. Kozaburo Miyakawa, *George E. Modesitt, *Robert B. Moler, Mohamed Wafik Morsy, Edward A. Murphy, Martin D. Nahemow, *Julian C. Nall, *Cecil A. Nanney, Ralph H. Nelson, Martin Nesenbergs, Jacob Neuberger, *Werner M. Neupert, *Robert H. Neusel, *Jan S. Nilsson, Kazuaki Nishimura, *Wilfred Glen Norris, *Lewis H. Nosanow, Albert G. Opitz, Florence J. Oswald, Henry Oswald, Paul M. Parker, Richard L. Perry, *Philip M. Platzman, Val W. Pratt, Thomas M. Proctor, Jr., Harold J. Quinn, Ronald J. Radda, Richard L. Raybold, William A. Read, Jr., R. Daniel Redin, W. H. Reid, *William P. Reidy, *Alan R. Reinberg, *Louis P. Remsberg, Jr., *Paul L. Richards, Burt Richardson, Ariel Tejera Rivera, Frank D. Roberts, *Charles M. Rockman, Basil Rose, *F. Merk Ryan, *Ehab M. A. Salam, Robert J. Salkeld, *D. J. Sandiford, *Antony F. Saturno, Sinclaire M. Scala, *Jerry Schachtschneider, *Daniel Schechter, *James R. Scherer, Thomas P. Schick, S.M., Eric C. Schluter, *Irwin Schneider, Burton G. Schuster, Stephen E. Seadler, Takashi Sebe, Henry Seiwatz, Carl A. Shiffman, *Takanori Shiozaki, *Edward N. Shipley, *David A. Shirley, *Bruce W. Shore, Merwin Sibulkin, *Seth D. Silverstein, *Jack Kent Sistler, Adam S. Skapski, Owen K. Skousen, John A. Sliter, *Robert R. Slocum, *Ranga Sreenivasan, Godfrey H. Stafford, Richard Stevenson, *Eugene Sucov, Masao Sugawara, Frank Tabakin, Shin Takeuchi, Shigeya Tanaka, Tetsuro Tanaka, Makoto Tanifuji, Ludwig M. Tannenwald, Rudolf K. Tenzer, *Richard B. Thomas, Jr., Walter J. Tomasch, *Ballard E. Troy, Jr., *Pbert N. Tufte, Edward F. Turner, Jr., Victor Vali, *Michael T. Vaughn, *Robin Verdier, *William G. Wagner, *Masami Wakano, *Edward J. Walker, John R. Walton, *Edward Y. Wang, John A. Weil, *N. Richard Werthamer, Edwin P. Westbrook, Helmut D. Weymann, A. Bruce Whitehead, Harold Wieder, *George P. Williams, Jr., *Jack Wong, Richard D. Worley, *Philip J. Wyatt, *Ian I. Yamanaka, *Amnon Yariv, Henry L. Yeagley, *Kwang Sik Yun, *Stanley A. Zemon, *Peter Gottlieb, John Owen, Robert B. Spooner, Arthur A. Westernberg.

Errata Pertaining to Abstracts C2, E6, EA5, GA1, H11, HA10, J5, MA3, U8, U10, and V5 of the 1958 New York Bulletin (Series II, Volume 3, No. 1)

C2, by F. Gürsey. In line 5, "ψ" should read "χ." In line 6, "$\psi=\frac{1}{2}(1-\gamma_4)p+\frac{1}{2}i(1+\gamma_4)p^c$ and $\zeta=\frac{1}{2}(1-\gamma_4)p-\frac{1}{2}i(1+\gamma_4)p^c$" should read "$\chi=\frac{1}{2}(1+\gamma_4)p+\frac{1}{2}i(1-\gamma_4)n^c$ and $\zeta=\frac{1}{2}(1-\gamma_4)p-\frac{1}{2}i(1+\gamma_4)n^c$."

E6, by Milton Green and Irving N. Greenberg. In line 18, "phototube (red sensitive) and a 919 phototube (violet sensitive)," should read "phototube (violet sensitive) and a 919 phototube (red sensitive),".

EA5, by P. W. Anderson. In line 15, "The second type certainly lies in the energy gap. They follow" should read "The second type follows."

GA1, by E. C. G. Sudarshan and R. E. Marshak. In lines 6, 8, and 12, "plus" should read "minus."

H11, by F. W. Terman and T. A. Scott. In line 11, "The apparent e^2qQ/h is 6.6 kc at 62°K, dropping to 5.4 kc at 53°K." should read "The apparent e^2qQ/h is 2.9 kc at 62°K, dropping to 2.4 kc at 53°K."

HA10, by F. S. Crawford, Jr., M. Cresti, M. L. Good, K. Gottstein, E. M. Lyman, F. T. Solmitz, M. L. Stevenson, and H. K. Ticho. The second entry under Column A of the Table, "1 ± 4," should read "10 ± 4."

J5, by V. K. Rasmussen, F. R. Metzger, and C. P. Swann. In line 3, "3000-Mev protons" should read "3.000-Mev protons." In lines 5, 8, 12, 13, and 17, "B'''" should read "B^{III}."

MA3, by F. J. Belinfante. In reference 1, "A Position Theory Without Holes" should read "A Position Theory Without Holes." In line 14, "four vector" should read "fourvector."

U8, by J. L. Yntema and B. Zeidman. In line 2, "The inelastic scattering of 2.6-Mev deuterons" should read "The inelastic scattering of 21.6-Mev deuterons."

U10, by Clyde B. Fulmer and Bernard L. Cohen. In line 7, "For atomic numbers $\gtrsim 50$" should read "For atomic numbers $\lesssim 50$."

V5, by A. B. Bhatia. In the last line, "small" should read "large."

The American Physical Society

OFFICERS OF THE SOCIETY FOR 1958

President	J. W. BEAMS	University of Virginia
Vice-President	G. E. UHLENBECK	University of Michigan
Secretary	K. K. DARROW	Bell Telephone Laboratories (*retired*) (Office at Columbia University)
Treasurer	S. L. QUIMBY	Columbia University
Managing Editor	S. A. GOUDSMIT	Brookhaven National Laboratory

Past Presidents now on Council: W. F. G. Swann, R. T. Birge, E. P. Wigner, and H. D. Smyth.

Elected Members of the Council: F. Seitz, A. M. Weinberg, S. K. Allison, N. F. Ramsey, Walker Bleakney, W. K. H. Panofsky, W. A. Fowler, and Charles Kittel.

Local Secretary for the Pacific Coast	W. A. NIERENBERG	University of California, Berkeley
Deputy Secretary	W. W. HAVENS, JR.	Columbia University

Please cut along this line

(To be sent to Dr. R. D. Huntoon, National Bureau of Standards, Washington 25, D. C.)

I EXPECT to attend the dinner of the American Physical Society at 7:00 o'clock on Friday evening, May 2. My party will comprise ..... persons.

(*Name*).....

(*Address*).....

If you want your tickets held to the time of the banquet itself, send a check for $4.50 per plate, made out to American Physical Society.

Memoranda

Memoranda

Memoranda

Memoranda